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BUREAU OF SOILS—BULLETIN No. 35.

MILTON WHITNEY, Chief.

ALKALI SOILS OF THE UNITED STATES.

A REVIEW OF LITERATURE AND SUMMARY OF PRESENT INFORMATION.

BY

CLARENCE W. DORSEY.

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FRANK D. GARDNER, in charge of Soil Management.
GEORGE T. MCNESS, in charge of Tobacco Investigations.
CLARENCE W. DORSEY, in charge of Alkali Land Reclamation.
JAY A. BONSTEEL, in charge of Soil Survey.
OSWALD SCHREINER, in charge of Fertility Investigations.

ASSISTANTS IN ALKALI LAND RECLAMATION.

W. W. MACKIE.
L. CARL HOLMES.
A. T. STRAHORN.
RUDOLPH BOSS.
J. F. WARNER.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., May 24, 1906.

Sir: I have the honor to transmit a manuscript entitled Alkali Soils of the United States—A Review of Literature and Summary of Present Information, prepared by Clarence W. Dorsey, of this Bureau. I recommend the publication of this compilation as Bulletin No. 35 of the Bureau of Soils.

Respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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ALKALI SOILS OF THE UNITED STATES—A REVIEW OF LITERATURE AND SUMMARY OF PRESENT INFORMATION.

ALKALI CONTENT OF ARID SOILS.

The climate of arid regions is directly responsible for the prevalence of sandy soils containing large stores of water-soluble materials, which at once become productive upon the application of water. Even the most desolate stretches of desert will supply good crops if the needed water is applied, as is shown by the millions of acres of land now under cultivation that were formerly a barren desert. While this is generally the case there are a few exceptions, one of the most striking of which is when the soil contains alkali. Frequently alkali[a] does not appear in an irrigated district until cultivation has been practiced for a number of years. The substances composing the alkali may be present in the soil before the application of water, or they may be brought in by the irrigation waters. In hot, dry weather, after rains or irrigation, the alkali frequently appears on the surface of the soil as a white crust.

Generally speaking, in most irrigated districts water is used in excessive amounts. Usually the farmer, seeing the benefits derived from irrigation, overirrigates his land, with the consequent damage arising from the accumulation of alkali salts and seepage waters. The accumulation of seepage water, either in pools or in sloughs, or filling the soil spaces of low-lying, poorly drained lands, is caused either by leakage through the sides and bottoms of the canals and laterals, or by excessive irrigation of higher-lying lands. Water in excess of the amount required by growing crops percolates downward, fills the soil, and finds its way through the more porous substrata to lower levels and local drainage basins.

As a result, we find few irrigated districts entirely free from the troublesome alkali after irrigation has been practiced a few years. Little provision is made for the drainage of lands when irrigating canals are built, as the country is then suffering from a lack of water. Traces of alkali may be noticed in places on the surface of the ground, or some of the characteristic alkali weeds may tell the experienced rancher that future difficulty may occur from the rise of alkali. Usually the amount of strongly impregnated alkali land is so small that little attention is paid to it, and as the ground water is many feet below the surface the need of drainage channels is not apparent. After a few years of excessive irrigation the water table rises. Capillary action pumps the water to the surface of the soil, where it evaporates, leaving the dissolved salts on the surface, where they accumulate to the detriment of the growing crop. Soon deep-rooted crops, such as alfalfa, begin to suffer from the rise of ground water, until they are completely swamped, while the areas of heavily incrusted alkali soils grow appreciably larger each year. Occasionally a single season suffices to transform a flourishing alfalfa field into a barren alkali flat. This is not the experience of a single irrigated district, but the common experience in all irrigated countries of little rainfall.

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[a] The term "alkali," as used in this bulletin, refers to water-soluble mineral salts which exert a harmful influence on vegetation if accumulated in sufficient quantity, and has no reference to the term as used by chemists. Chemically considered, the various kinds of alkali of arid regions are salts.

Thus it is seen that one of the drawbacks to irrigation farming is the liability to damage resulting from the rise of alkali and seepage waters unless reasonable precautions are taken. If provision were made for carrying away the surplus of water when the irrigation canals are built, the trouble from these sources would be reduced to a minimum. By using as little water as possible, with frequent cultivation of those crops that leave the soil partly uncovered, the danger from accumulations of alkali is lessened. Cultivation materially checks surface evaporation, while the restricted use of water reduces the chances of the deep subsoil becoming saturated so soon after irrigation is commenced. Unfortunately, however, few such provisions are made, and the alkali question becomes more serious from year to year. Even in districts suffering most from this cause little effort is made to check the spread of alkali. Often through lack of knowledge of how to fight the evil or from disinclination to combat it the farmer abandons his land. In many districts, what were formerly the choicest tracts of land are now alkali flats or salt-grass pastures. In some districts land values have depreciated from several hundred dollars an acre to a merely nominal value. Conservative estimates show that about 10 per cent of the irrigated land in the arid regions of the United States contains so much alkali as to be practically unfit for cultivation to any but the most alkali-resistant crops. In 1902 the United States Census Bureau gave the amount of irrigated land in the arid States and Territories as 8,471,641 acres. Ten per cent of this is, approximately, 847,000 acres. Placing a valuation of $50 per acre on this land, a very conservative estimate, we find that the West has lost lands valued at more than $42,000,000 on account of alkali. This shows the enormous damage already caused, and the evil increases from year to year.

COMPARISON OF SOILS OF ARID AND HUMID REGIONS.

The question naturally arises why arid soils alone should suffer from alkali. This is easily answered when we study the origin and formation of soils in different parts of the country. One of the most striking characteristics of the soils of arid or semiarid regions is the large amount of water-soluble material contained in them. This is in decided contrast to the soils of those regions where copious rains occur the greater part of the year. Soils consist of more or less finely divided rock fragments which have been acted upon to some extent at least by the weathering influences of climatic agencies. Of the agents that operate to transform the various kinds of rocks into soils we find that water is one of the most powerful. Running water, with its enormous transporting and abrasive capacities, is a potent agent in forming soils by mere mechanical processes. Freezing water, by disrupting or tearing asunder rock masses, is another important factor in soil formation. Rain water is a great solvent and acts upon rocks to change them into soils, dissolving out their component parts. As rain water is never found pure, but always carries carbon dioxide, which increases its solvent power, it leaches out the most easily dissolved substances and carries them away. Chemical examination of the waters of springs, lakes, rivers, and the ocean shows them to contain variable amounts of saline material which have been dissolved from rocks. Other agents, such as changes of temperature, wind action, the effect of small forms of animal and vegetable life, as well as many chemical actions, also hasten the process of reducing rock masses to soils capable of supporting vegetation.

The influence of the forces tending to form soils varies greatly in different parts of the world, depending largely upon the climatic conditions. Rock decomposition advances more rapidly and completely in tropical countries receiving an abundance of warm rain, while in elevated plateaus with little or no rainfall the formation of soils takes place more slowly. In the first case the most insoluble parts of the parent rocks predominate in the resulting soils, while in the arid countries the soils are merely broken rock fragments that frequently have almost the same chemical composition as the original rocks.

Thus we find that in the arid and semiarid countries the composition of the soil is quite different from that of the humid countries receiving rainfall sufficient to grow crops without irrigation. The soils of the dry desert countries are rich in salts that yield the mineral nutrients for plants, while to a large extent these minerals have been leached out of the soils in those regions receiving abundant rainfall. Analyses show that the soils of arid regions contain many times as much magnesium and lime as the soils of humid regions. As the content of lime in the soil is frequently indicative of its productive capacity, the large amount of this material found in arid soils is a strong point in their favor and is verified by their wonderful fertility when irrigation water is supplied. Again, the amount of potash and soda found in the soils of arid countries is largely in excess of that contained in soils where rainfall is abundant. In the case of phosphoric acid, another very important soil ingredient, there is little difference between the amount contained in the soils of humid and arid regions. The amount of humus found in arid soils is quite low. Sandy or light-textured soils are the rule in regions of little rainfall, but they are very retentive of moisture—far more so than the soils of similar texture in humid countries.

ORIGIN OF ALKALI.

The origin of alkali is, in general, uncertain, although it has been the subject of much speculation, and a number of hypotheses concerning it have been advanced. These hypotheses are, as a rule, open to serious objections, and brief mention only of the more prominent ones will be given.

In a few cases the genesis of alkali can be clearly traced. For instance, in the Billings area, Montana, where the alkali is almost entirely a mixture of sulphates of sodium with lesser amounts of magnesium sulphate, it seems obvious that the source of the material is found in the sulphides of iron prevalent in the Fort Benton shales, which on exposure to the air oxydize to the sulphates and then on contact with water hydrolize, forming sulphuric acid and ultimately the sulphates of the alkalies and alkaline earths. In other cases deep-seated springs, yielding water carrying salts or even free mineral acids, such as hydrochloric or sulphuric acids, can be regarded with much probability as the origin of the alkali. But such cases are usually sporadic and of relatively unimportant extent.

In by far the greater number of cases throughout the world where alkali or similar accumulations of soluble salts occur, the predominating salt is sodium chloride, with lesser amounts of other chlorides, sulphates, and sometimes carbonates. Occasionally other salts are present, but rarely in significant amounts.

This mixture of salts, resembling so closely that contained in sea water, naturally suggests the latter as the origin. In some cases it may be regarded as fairly evident that the salts do come from more or less deep-seated deposits resulting from the desiccation at more or less remote periods of time of bodies of sea water. In many cases, however, there is a total lack of confirmatory geologic evidence, and this explanation must be regarded as very unsatisfactory.

It has been suggested that some of these deposits may be the result of wind-blown spray from pelagic sources. The enormous distance to which it is known that dust is sometimes carried to sea lends probability to this hypothesis. But it is difficult to see how such wind-blown masses could pass high mountain ranges without precipitation, and it is even more difficult to see why there should be the excessive precipitations in any one area which would be necessary to account for the large masses of salts in these accumulations.

Another hypothesis has been suggested by Dr. Frank K. Cameron, of this Bureau, which has the merit of having a wide general application and seems to be in entire accord with well-known soil phenomena. As it has not, so far as we are aware, been advanced hitherto, it is given here in some detail.

The major part of the complex crystalline masses or rocks forming the earth's crust contain chlorine and sulphur. F. W. Clark[a] gives as an average 0.07 per cent chlorine and 0.108 per cent sulphur. As a result of the hydrolizing action of water[b] and other decomposing agencies, probably all the chlorine and very much of the sulphur is converted into hydrochloric acid and sulphuric acid, which in turn form the corresponding salts of the alkalies and alkaline earths. The aggregate amount which is thus being constantly formed in the subsoils and underlying strata of any one area must be very large. As evaporation proceeds at or in the surface soil, there is a rise of the water in the underlying layers through the capillary spaces toward the surface, bringing with it the hydrochloric and sulphuric acids or their salts.

The sulphuric acid moves up more slowly than does the hydrochloric acid, partly, perhaps, because the rock masses and the soils have a greater absorbing action on sulphuric than on hydrochloric acid, tending to withdraw it from solution; partly, perhaps, because reducing conditions may exist in some layers tending to the formation of metallic sulphides, and partly, undoubtedly, to the formation of the slightly soluble calcium sulphate. This last, however, is gradually brought toward the surface, and is often found in enormous masses at slight depths in the soils of arid regions. Undoubtedly the calcium carbonate so generally found in large masses at moderate depths in the soil of arid regions originates in a similar manner.

Hydrochloric acid is transported through soils and most absorbing media with comparative ease. Moreover, the chlorides of the alkalies and alkaline earths are readily soluble. Chlorides should be expected, therefore, to accumulate in preponderant masses at the surface, which under arid and semiarid conditions they generally do.

The preponderance of sodium chloride over other chlorides is readily explicable. It is well known that when solutions of chlorides are poured through columns of soil or similar substances, offering a large surface of contact to the solution, there is a well-marked selective absorption, the soil tending to withdraw the base from the solution to a decidedly greater extent than the acid, with the result that the leaching generally contains free acid. So far as the experience we have goes, it would seem that in general soils absorb potassium most readily, then magnesium, calcium, and sodium in the order named. Supposing the hydrochloric acid when found in the lower layers to be neutralized with a mixture of these bases, as it rises in the capillary movement there is always a tendency, owing to the selective absorption of the soil, toward a lagging behind of the potassium, a lesser lagging of the magnesium and calcium (these bases probably tending also to form the much less soluble sulphates and carbonates) and a much less lagging of the sodium. In consequence, sodium is the predominating base in the readily soluble salts at the surface.

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[a] Bul. No. 228, U. S. Geological Survey, 1904.

[b] Bul. No. 30, Bureau of Soils, U. S. Dept. Agr., 1906.

The interaction of rain and irrigation waters and the sodium chloride in the surface soils with the gypsum or limestone, or both, usually found in large masses at slight depths, with the formation of the sulphates or the carbonates of sodium, and the chemical classification of alkali upon this basis is discussed elsewhere and only needs passing mention here.

To sum it up, it must be concluded that our knowledge of the origin of alkali is not yet thoroughly satisfactory and that additional laboratory and field observations are needed before a definite statement concerning this subject can confidently be made.

KINDS OF ALKALI.

Alkali is most commonly spoken of by irrigation farmers as white alkali or black alkali, depending on the color of the incrustation on the surface of the soil. This classification will probably always continue in common use, but it is not altogether satisfactory. The substances which form the alkali of arid countries are mainly the chlorides, sulphates, and carbonates of sodium, calcium, and magnesium, or a mixture of two or more of these salts. Other substances may occasionally be found, but they are relatively unimportant. Generally speaking, alkali consists of three principal ingredients—common salt or sodium chloride, Glauber's salt or sodium sulphate, and sal soda or sodium carbonate. Sodium carbonate is the principal ingredient in black alkali, and on account of its corrosive action on vegetable matter usually makes a brownish or black stain on the soil; hence the name black alkali. Since sodium carbonate may occur in large quantities in the soil and yet no dark color appear, but a white incrustation instead, the name black alkali is apt to be misleading. Again, some of the lime salts (calcium chloride) may impart a dark stain to soils, and while the injurious effect of this salt is not comparable with that of sodium carbonate, yet because of this dark stain it is usually considered black alkali by the irrigation farmer. In the accumulations commonly known as white alkali no sodium carbonate occurs; the color is not always white and the name is also apt to be misleading.

In making maps to show the distribution of alkali the practice in this Bureau has been to classify an alkali as white when no sodium carbonate is present and as black when this salt is found in the soil in considerable quantities. Since the sodium salts largely predominate, the various classes of alkali are commonly referred to as simply chlorides, sulphates, or carbonates. These salts are especially distinguished because they differ greatly in their effect upon growing vegetation; the carbonates are most toxic or injurious to plant growth, while the sulphates are least injurious.

ACCUMULATION OF ALKALI IN THE SOIL.

The accumulation of alkali in the soil, whether at the surface or many feet below, is an interesting process and deserves much more detailed consideration than has yet been given to it. The conditions which have caused accumulation vary considerably in different districts. In some places it is found that large accumulations of alkali have occurred at the surface; in other districts the accumulations are lodged several feet below the surface, and these conditions have been observed before the use of irrigation water. In many districts little or no alkali was apparent in the soil until irrigation was practiced, but with irrigation alkali accumulations began to appear and to increase continually so long as irrigation was carried on.

As has been shown in the comparison of the soils of arid regions with those of humid regions, the former contain large stores of water-soluble mineral matter. Hilgard, as a result of studies in California, states that few upland soils in the arid regions of that State contain less than from 2,000 to 2,500 pounds of soluble salts per acre in the first 4 feet. The only time this soluble mineral matter can move about through the soil is when it is dissolved in water. Means, in the report of the soil survey around Fresno, Cal., has discussed quite fully the ways in which salts move within the soil, and the following account is largely adapted from that report:

MOVEMENT OF ALKALI SALTS WITHIN THE SOIL.

The movement of alkali salts may be caused (1) by diffusion in the soil moisture, (2) by the force of gravity in moving the soil moisture downward, (3) by surface tension or capillary action, which moves the soil moisture in any direction.

(1) *Diffusion.*—The diffusion for salts or mixtures of salts in the water is so low that compared with the movement by gravity and surface tension the effects are practically negligible.

(2) *Force of gravity.*—When water is applied to the surface of the soil the force of gravity, assisted by surface tension, pulls the water

down into the capillary spaces. Soils will hold a certain percentage of water by capillary forces alone, and any excess over this percentage will drain away. This excess is called gravity water. When the surface of the ground is flooded, both surface tension and gravity act in pulling the water downward. Since the rate of flow of water through capillary spaces depends upon the size of the space, the flow through the large capillary spaces, root holes, worm borings, and animal burrows is very much greater than that through the true capillary spaces. When water is applied, the downward movement by gravity is almost entirely through the larger noncapillary spaces, while the true capillary spaces are filled by surface tension from the noncapillary spaces. In this way the salt which is dissolved by the descending water is probably to some extent drawn back into the capillary spaces, where there is very little downward movement, and remains there, only escaping out into the channels of downward movement by diffusion. The amount of salt which is washed downward by a heavy flooding is therefore not so great as would be expected.

(3) *The greatest movement of alkali salts is due to capillarity which operates through surface tension.* When water moves by surface tension, the films around the soil grains move. As soon as the gravity water has drained away, the movements become entirely by surface tension. A loss of water due to evaporation changes the curvature of the water films and starts a capillary movement toward the point where the evaporation takes place. But when water moves by capillary action it is the water in the smaller spaces that moves, and not the water which is in the larger noncapillary spaces. Therefore the water which was drawn back into the capillary spaces and which carried some of the alkali salts as it flowed down into the soil starts upward and carries with it the salts in solution. The evaporation of an inch of water on the surface of the soil accumulates on the surface all alkali salts which were contained in that inch of water, while, on the other hand, the same volume of water leached down through the soil would probably not leach out an equal amount of the salts. From this it will be seen that the tendency of the alkali salts under irrigation is to move upward perhaps more rapidly than downward.

From the above discussion it appears that surface tension or capillary attraction, as it is commonly called, is the most important agent in the movement of alkali salts toward the surface of the soil. Therefore, a soil which would permit the most rapid movements would be the most likely to accumulate alkali salts upon the surface. If two soils with different capillary powers were placed side by side, with the level of standing water the same, the soil which raised the water to the surface the more rapidly would the sooner accumulate an alkali crust.

POSITION OF MAXIMUM SOLUBLE SALT CONTENT IN THE SOIL.

In an arid or semiarid region, with the water table many feet below the surface, the bulk of the soluble salts will usually be found some distance from the surface of the soil, depending to some extent on the depth to which the annual rainfall penetrates. This means that the rainfall is not sufficient to wash the soluble salts originally contained in the soil to any great depth, but is sufficient to wash the salts down from the upper part of the soil. In sandy loams, where the rainfall does not penetrate to any considerable depth, the great quantity of salts will be found from about 3 to 4 feet. In the case of a coarse sand soil in the same district the rainfall will penetrate deeper, and therefore the salts will be washed to a greater depth, probably from 4 to 8 feet. These approximate depths at which the bulk of the salts was found were observed by Means in the Fresno, Cal., district, with an annual rainfall of about 8 inches. In the Imperial Valley, California, Holmes found the greater part of the alkali salts in virgin soils at a depth of 18 inches. In this district the rainfall is about 3 inches. In Ventura County, Cal., with an annual rainfall of about 15 inches, in sandy loam soils in their natural state, Holmes found the bulk of the soluble salts at a depth of 5 feet. In the Grand Forks area, North Dakota, with an average rainfall of nearly 20 inches, Jensen found the greater part of the soluble salts accumulated below a depth of 3 feet. These examples are given to show that in a level country with a deep water table the rainfall leaches the salts to a greater or less depth, according to the amount of rainfall and whether or not the soil is easily penetrated by the rain water. Upon evaporation of the soil moisture some of the dissolved salt returns to the surface, but as not all of the rainfall is returned by capillary action to the surface and evaporated, the greater part of the soluble salts tends to accumulate at the limit of penetration of the rains. If all of the rain water entering the soil were returned to the surface and evaporated there, accumulation of alkali at the surface would be the rule, but evaporation takes place in the soil below the surface, and the salts are held at the point of evaporation.

The high temperature which prevails in many parts of the arid regions, together with the long periods of drought, combine to keep the surface soil in a dry condition. For the greater part of the year, therefore, the capillary water column fails to come to the surface of the soil. Under such conditions it is evident that any evaporation which occurs must take place within the soil at the top of the capillary column, the water vapor escaping by diffusion through the layer of the dry soil above. Recent determinations made in the laboratory of this Bureau have shown that an evaporation of this kind does take place within the soil. Since the dissolved salts can not rise above the point where evaporation is taking place, an accumulation of salts must take place within the soil at the upper end of this capillary column. The depth of the top of this capillary column below the surface of the soil (and consequently the depth of the accumulated salts) will depend upon the ease with which the water vapor may escape by diffusion to the air above—that is, upon the porosity of the soil. We should expect, therefore, that in porous sandy soils the greatest accumulation of soluble salts would be found at a greater depth than in the case of soils of finer texture, and this accords well with field observations. This condition would result not only from the greater porosity of the sandy soil, but also from the lower capillary power of the coarser material, which would enable capillary connection with the surface to be more readily broken.

When we consider the fact that the mulching of the surface soil is used to prevent evaporation, it may appear strange that sufficient evaporation could take place through a layer of soil several feet in thickness to produce an accumulation of salts. But it must be remembered that these deposits may have been accumulating for centuries under the hot, dry environment most favorable for action of this kind.

In an arid or semiarid region it is easy to see that surface accumulations of alkali will be found in those districts where the ground water is sufficiently near the surface to permit the continuous capillary movement of the soil moisture to the surface. In such cases not only will the soluble material contained in the soil be accumulated by evaporation at the surface, but also the dissolved salts held in solution by the shallow ground water. And so we generally find basinlike depressions surrounded by sloping lands incrusted with heavy coatings of alkali. In this case the drainage from the slopes is toward the low ground and, with a permanent capillary connection between the moist subsoil and the surface, the surface in time becomes heavily incrusted with alkali.

PROBLEM OF THE FARMER IS TO PREVENT ACCUMULATION OF ALKALI AT THE SURFACE.

Having in mind the above discussion of the movement and position of the soluble salts in arid soils under natural conditions, it is at once seen that the most important problem for the irrigation farmer is how to prevent the accumulation of these soluble salts beyond the danger point or, having a surplus already accumulated in the soil, how most economically to remove this surplus and bring the soil to a profitable state of cultivation.

It is true that not all of these soluble salts are equally injurious, and none of them is detrimental to field crops when present in very small quantities. It should be emphasized that it is the accumulation that causes damage. It is also evident that, whatever the nature of the soluble salts, they may be washed out of a porous soil if conditions be such that water may be applied to all of the surface, and after leaching through the soil be carried away in the country drainage. Not all the water applied to the surface will leach through the soil, even under most favorable conditions. A part will unavoidably be returned to the surface to be evaporated, and if vegetation exists still another part will reach the air through the plants, great quantities of water being necessary for their growth. The principles that should guide the farmer in the handling of all irrigated lands under arid or semiarid conditions that favor the local concentration of salts may be briefly stated as follows:

Apply to the surface of the soil all waters that supply the crops with moisture, when it is known that the soils contain appreciable quantities of alkali. Under no conditions whatever should one depend upon subirrigation, seepage, or percolating waters to supply the crops. It is recognized that surface irrigation is a wasteful method of applying water, but it is strongly to be recommended to overcome the inevitable rise of the salts contained in the soil.

In the growing of fruits, grapes, or tilled annual crops, such as melons, corn, and truck crops, it may often be the best practice to apply the bulk of the water by the furrow method of irrigation. At best this method is one kind of subirrigation, and should only be practiced where the annual rainfall is sufficient to wash out the salts that must accumulate at the surface in the spaces between the furrows or in the tree rows; or, where this rainfall is insufficient, furrow irrigation should be accompanied by periodic smoothing and flooding to leach the salts downward. Therefore, the first requisite is so to control the application of the water that the main movement of the water will always be downward, and for at least a part of the time downward over the entire surface.

In every practicable way prevent evaporation from the surface. It has been shown that even with the most careful methods of application of water a part will be evaporated from the surface. When the water supply is so small that flooding becomes expensive, it is often more economical to cultivate thoroughly in order to retard the rise of the salts to the surface in the fields tilled, and thus lengthen the time between successive smoothings and floodings. Careful and frequent cultivation will produce a mulch that will do much to retard evaporation.

If crops are grown that admit of flooding in the application of water, there will be no danger of an accumulation of alkali, provided (*a*) the whole surface be covered with water during floodings and (*b*) the level of standing water be not so close to the surface as to permit the capillary power of the soil to make connection between this ground water and the surface of the soil. One of the most fruitful causes of alkali spots in any region given over to general flood farming is the carelessness on the part of the farmer in not thoroughly smoothing his land before beginning operations. If there be high spots, these are subirrigated whenever the remainder of the field is flooded; and, as in the case of furrow irrigation, the salts thus accumulated remain unless washed out by the rainfall or by artificial applications of water. In many cases the rainfall is insufficient to do this, and artificial applications of water or irrigation is impossible until they are smoothed.

When the water table is so close that capillarity can bring the water to the surface, the greatest care must be exercised to prevent evaporation. Not only must all the above precautions be taken, but the soil must be watched at all times and the surface mulch be maintained upon the removal of the crop. In many of the soils of the arid regions, especially in the fine sandy loams that are so prevalent, the capillary powers are very great, and the rapidity with which water moves through the soil is correspondingly great. Briggs[a] has shown that the height to which water will move in a moist sand is about 4.5 times as great as the same movement in a dry soil. His researches show that in a moist sand water will be raised more than 5 feet. For these fine sandy loams it will be readily seen that the height will be much greater, so that the surface evaporation and consequent accumulation of alkali will, if not checked by farm practices, take place rapidly in these soils when the water table is so far beneath the surface as not in itself to injure ordinary crops. These fine sandy loams are often found in their virgin state with a high percentage of alkali, yet with the water table at from 9 to 12 or even 15 feet below the surface, while adjoining sandier soils with the same water table are comparatively free from salts. In such instances it is obvious that more careful treatment is necessary for the fine sandy soils than for the coarser ones.

SUBIRRIGATION THE MOST FRUITFUL CAUSE OF SURFACE ACCUMULATIONS OF ALKALI.

In this connection it is perhaps advisable to emphasize the fact that subirrigation is one of the most fruitful causes of surface accumulations of alkali salts. The average man who starts farming on dry alkali-free soil has no thought but to supply his crops with sufficient moisture. All his efforts are to accomplish this, which to him seems the greatest problem in cultivating arid soils. If he is so situated that the irrigation taking place on higher lands with its accompanying seepage raises his water table to within capillary reach of the root zone of his crops, he suddenly finds his greatest problem apparently solved. He no longer has to irrigate to supply his crops with moisture. If the roots of his crops are not actually submerged, the first effect of this subirrigation is to increase enormously his yields of crops, and he hails with joy this new order of things that has minimized his labor and multiplied his yield. The percolating waters have taken up soluble salts, some of which are those needed by crops, but the greater quantity of which are the salts forming alkali. Supplied at all times with a favorable amount of moisture and with mineral nutrients in abundance, it is small wonder that the first stages of subirrigation are marked by record-breaking yields. But little by little the evaporation from the surface causes an accumulation of soluble salts. The slight rainfall carries a part of these salts downward into the soil, but seldom is this sufficient to carry them to the percolating sheet of water below, and the capillary rise again tends to carry them to the surface. So, nearly all the salts left behind by evaporation remain in the soil. The rate at which the salts accumulate will depend upon the amount of water the soil can raise to the surface. This amount will be greatest in a fine sandy loam, for in such a soil nearly all the spaces are capillary spaces, and yet the soil is not so dense as to offer great resistance to the movement of water. Thus under conditions of subirrigation it is always these soils that carry the greatest accumulations of alkali, and they are always the first to suffer. But in any case where the soils are not actually swamped the accumulations are so gradual as not to cause alarm until the soils are so affected that some spots cease to be productive. If the remainder of the field continues to produce fair crops, the farmer seldom recognizes the true cause of these unproductive spots and continues to depend upon subirrigation. The ultimate ruining of the land is inevitable. This period of inactivity of the irrigator on lands that are subirrigated, yet do not actually need artificial drainage, is the ruin of by far the greatest percentage of lands that were once productive, but now contain alkali beyond the point of endurance of the crops.

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[a] Capillary studies and filtration of clay from soil solutions, Bul. No. 19, Bureau of Soils, 1902.

The discussion so far has dealt mainly with ordinary irrigated soils, in which it is assumed that there are no harmful accumulations of alkali at the beginning of the operations.

The same rule—the application of all waters to the surface so as to insure a downward movement, and the prevention as far as possible of evaporation from the surface—applies to the reclamation of alkaline lands as well, except that in this case no method of applying water except flooding should be used. If such precautions as outlined above be taken, lands originally free from salts should remain so, and alkali lands should steadily become better, provided the regional drainage of the country be good.

The general discussion of the reclamation of lands heavily impregnated with alkali will be considered in another part of this paper.

INJURIOUS EFFECTS OF A FLUCTUATING WATER TABLE.

One making a study of the subject of the drainage and reclamation of alkali lands can not help but be impressed by the fact that not in all cases is the entire damage due to alkali. Because of the great depth of the soil in all arid regions, fruit trees, vines, alfalfa, and other perennial crops, as well as the ordinary annuals, develop a much deeper root system than is the case in humid regions. In the case of annuals very little damage is done by the water table itself, for the crops can each year develop a root system that will be best suited to the moisture zone. But in the case of the perennials this is not so. Many instances are on record where, with a low water table, alfalfa, grapes, and fruit trees have sent their roots down to great depths. With a light soil and favorable conditions many of the feeding roots of such plants are from 4 to 8 feet below the surface. If from any cause the water table is raised and submerges these roots, the plants will immediately show signs of suffering. In fruit trees this is usually manifested by "die-back" in the new growth, or if the rise be rapid, so that they can not develop new feeding roots above the water, the trees may be killed. Grapes show the effects of this ground water by a stunted growth, but readjust themselves more quickly than trees and are seldom entirely destroyed. Alfalfa turns yellow, gradually dies out, and the field may become entirely barren. Few of the common crops grown in arid regions will maintain a root system that is actually submerged in water, nor will they send their roots into the water. Often orchards may be observed in a very bad condition, with the trees struggling for life because of the encroachment of the water table upon their root systems, while orchards of the same trees on similar adjoining lands are in a thriving condition, the latter having been planted since the rise of the water table, and hence having developed their root system above the water table. Alfalfa fields that have been killed out by the rise of the water table may often be reseeded and will produce a good crop, because of the shallow development of the new root system. Thus it is the fluctuation rather than the shallowness of the water table that causes damage directly to the plants.

If the fluctuation be annual or periodic the difficulty of maintaining cultures that have a tendency to develop a deep root system in seeking the most favorable moisture conditions is greatly increased. At each subsidence of the water the feeding roots follow down, to be swamped at the succeeding rise. Thus it will be seen that a fluctuating water table within the possible zone of root development is in itself a serious menace to perennial crops. Walnut trees have been observed in southern California that were suffering from submerged roots when the water table was below 12 feet, while a few miles away trees over 30 years old were in excellent bearing condition on land that had never had a water table below 6 feet. At Fresno, Cal., many orchards have died when the soil showed such small amounts of salts that the damage could not have been from alkali. Near Tempe, in the Salt River Valley, Arizona, fruit growing has almost ceased because of the killing out of the older orchards by the ground water, even on practically alkali-free lands. Instances might be multiplied where injury has resulted from this cause. There is hardly an irrigated district where perennials are grown that could not furnish such specific testimony.

Investigators have frequently overlooked this important feature of the problem, and have attributed all the injury to the rise of alkali. There can be no question that this feature is of vital importance. Since it is so closely allied to the alkali problem it seems just to consider the two together. Any method that would improve the alkali condition but aggravate this evil would necessarily result in limiting the number of crops that might be grown. Moreover, fruits and alfalfa are at the present time the main crops of the irrigated regions, and the object of reclamation is very often to enable these crops to be grown. Since it is the fluctuation of the water table that causes damage from water alone, and since it has been shown that lands not drained below the reach of capillarity may be reclaimed from alkali, it must appear that, considering the two problems jointly, the method of treatment that will prevent fluctuation of the one, and at the same time result in reclamation from the other, is the most desirable. Thus considering jointly the problem of alkali and fluctuating water table, as well as the means for lowering the water table, it will be seen that the least fluctuation will take place where gravity drains are used. Pumping plants will usually be operated periodically, and hence will allow of fluctuation. Unless the water be lowered beyond the reach of the roots of plants and the fluctuations thus take place below the root zone, drainage by means of a pumping plant, while it would permit of the reclamation from alkali, would aggravate the injury from seepage water. To accomplish the desired object with gravity drains they should be constructed in sufficient detail to remove readily any surplus of water that might at any time be added to the district. The detail necessary to do this will be dependent upon the nature of the soil and subsoil and the sources of accessions of the ground water. If much of such water comes from seepage from canals, cut-off drains to catch this seepage may be a partial preventive. But in every case the detail must be worked out for the individual area, keeping in mind this two-fold object of drainage.

RESISTANCE OF PLANTS TO ALKALI.

Just what amounts of the various kinds of alkali can be endured by different plants has been the subject of investigation for many years. It has long been known that some plants—as, for example, young alfalfa—are very sensitive to alkali, while other plants, such as sorghum, can be grown on land containing so much alkali that it would be fatal to the more sensitive plants. Again, we find that not all of the soluble salts commonly called alkali exert equally injurious effects on cultivated plants. Thus black alkali, or sodium carbonate, is most dreaded by farmers of irrigated districts on account of its corrosive action on vegetable matter, while, on the other hand, they recognize that some of the forms of white alkali are not especially injurious unless accumulated in excessive amounts. Under natural conditions the experienced farmer learns to judge land by the vegetation that flourishes prior to irrigation. The growth of some bushes, he has learned through observation and experience, indicates that the soil contains accumulations of alkali, even though it may not appear on the surface. Other natural vegetation tells the farmer that the soil contains no alkali. In the States of Montana, Wyoming, and Idaho greasewood (*Sarcobatus vermiculatus*) is considered indicative of alkali in the soil, although there may be no surface manifestations denoting its presence. In some districts, however, the farmer has learned that only the abundant growth of small stunted greasewood denotes alkali in the soil, while a large-sized, scattering growth of the same plant means an alkali-free soil. Not all of the native grasses and plants can be taken as an absolute indication of the presence or absence of alkali. The common salt grass (*Distichlis spicata*) is usually considered indicative of at least some alkali in the soil, yet it has been found growing on alkali-free soil. Again, it has been observed that in one locality the plants and weeds may be regarded as denoting certain conditions of soil as regards alkali, while in other localities the same growth may not indicate similar soil conditions, but perhaps the very opposite. And so while in general the relations of plant life to alkali have been worked out, the exact amounts of alkali that can be tolerated by various crops is a problem much more difficult, and as yet not altogether understood. As Loughridge[a] has pointed out, there are many conditions which confuse the problem, such as climatic conditions, the possible presence of insects or diseases, imperfect physical condition of the soil and subsoil (hardpan, for instance), high-water table, shallowness of soil, lack of ventilation and aeration, poor moisture supply, etc. The variability in the composition of the alkali still further confuses the problem. Then, too, while we may find a crop growing on certain soil which shows on analysis a certain percentage of alkali, we have no definite knowledge that the soil in direct contact with the small feeding roots contained a similar alkali content. A given soil that contains a certain amount of alkali may support a good growth of a crop, but unless the life history of the crop is known no definite statement can be made as to the amount of alkali that was present in the soil at the various stages of the plant's growth. For example, in the Bear River Valley, Utah, Jensen found sugar beets growing on soil that contained upward of 3 per cent of alkali—mainly sodium chloride—in the surface foot of soil, with smaller amounts in the soil below this depth. From this we can not assume that the sugar beets actually withstood 3 per cent of alkali, for at the time the young beets were started heavy rains and irrigation had leached so much alkali from the soil that it contained no more than could be tolerated by the young plants. The large accumulation in the surface foot took place later in the season, and at the time the examination was made the beets were undoubtedly drawing their moisture supplies from the second foot, where the soil did not contain excessive amounts of alkali.

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[a] Tolerance of alkali by various cultures, Cal. Expt. Sta. Bul. No. 133.

The texture of the soil must be considered in determining the resistance of crops to alkali. With equal amounts of alkali in a sandy and clay soil in the same district crops will suffer more on the sandy soil. This is because the sandy soil retains a smaller amount of moisture than the clay soil, and the soil solution is more concentrated and is more easily able to exert a toxic effect on plants.

Of the sodium salts—usually the predominating salts found in alkali soils—carbonates are the most injurious, chlorides come next, while sulphates are least injurious to plant growth. Since it is seldom that one of these salts constitutes all of the alkali found in soils, it is difficult to determine definitely under field conditions the exact amount that can be endured by different plants. In the Baker City area, Oregon, Jensen obtained results that are of interest as showing resistance to alkaline carbonates. Here he found oats growing well with 0.08 per cent in the soil at the root crown, traces of neither chlorides nor sulphates being present, while in other places he found that less amounts were injuring the crop. With sulphates present it was found the crops would not stand as much of the alkali carbonates. Perhaps some of the sulphate was magnesium, a salt which Kearney and Cameron[a] found to be more injurious in pure solution than sodium carbonate. Wheat in this area was found to be growing well with 0.04 per cent alkaline carbonates in the soils. Alfalfa was likewise making good growth on soil with 0.08 per cent alkali carbonates, but the crop had been established for some time. These figures serve to give an idea of the endurance of plants in this particular area and show that from 0.03 to 0.08 per cent was about the range of amounts that could be tolerated by crops under field conditions.

In making alkali surveys in the different areas it is the custom of this Bureau to divide the land into six different grades, the relative extent of each grade of alkali land being shown on colored maps.

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[a] Report 71, U. S. Department of Agriculture.

The soils of these different grades contain from 0 to 0.20 per cent of total salts and less than 0.05 per cent of black alkali; from 0.20 to 0.40 per cent of total salts and from 0.05 to 0.10 per cent of black alkali; from 0.40 to 0.60 per cent of total salts and from 0.10 to 0.20 per cent of black alkali; from 0.60 to 1 per cent of total salts and from 0.20 to 0.30 per cent of black alkali; from 1 to 3 per cent of total salts and more than 0.30 per cent of black alkali, and more than 3 per cent of total salts—this scale representing the average of the quantity of salts contained in each foot to a depth of 6 feet. Generally it has been the experience of field parties that on land containing from 0 to 0.20 per cent of total salts none of the common crops are injured unless carbonates greatly predominate or unless practically all of the salt is concentrated in the upper part of the first foot. On land containing from 0.20 to 0.40 per cent of total salts and from 0.05 to 0.10 per cent of black alkali all but the most sensitive crops will grow, but near the higher limit all classes of plants excepting those truly resistant show signs of distress, and if the condition remains unchanged the death of the plants sometimes results. Alfalfa, when well started, grows on this class of land, but it is often difficult to secure a good stand. Sugar beets, sorghum, and barley may be grown with profit, provided precautions are taken in starting the crop. Often a heavy irrigation before seeding will result in the movement of the salts toward the subsoil, and by the time they return to the surface the crop may have sufficient stand and vitality to endure the injurious effects of the salts.

The grade of land containing from 0.40 to 0.60 per cent of total salts and from 0.10 to 0.20 per cent of black alkali contains a little too much salt for the common crops. Such lands are generally devoted to pasture, although in some areas, by thorough preparation of the seed bed, and by heavy irrigation to insure a downward movement of the salts, sorghum, sugar beets, and alfalfa have been made to produce partial or full crops. Generally only the most resistant fruits will succeed on lands of this character.

Soil containing from 0.60 to 1 per cent of total salts is almost worthless for general farming or fruit growing, but by continued effort some of the most resistant crops may be grown. The last grades are likewise worthless for farming purposes. It should be stated, however, that even with an average of 3 per cent of salts in 6 feet of soil conditions may be such that crops can be grown, much depending upon the position of the salt in the 6-foot section, whether it is evenly or irregularly distributed. By copious irrigation crops may be started and even matured on land containing 3 per cent of alkali, provided the maximum alkali content is in the lower part of the 6-foot section and evaporation at the surface is so checked that the alkali does not accumulate at or near the surface. With such excessive amounts of alkali as 3 per cent in the soil to a depth of 6 feet the chances for surface accumulation are very favorable, and generally such land has no value for farming purposes.

Of the crops usually grown in the irrigated districts of the West, Kafir corn, sorghum, sugar beets, and barley are probably the most resistant to alkali. Kafir corn and sorghum are especially important in districts containing alkali, since they will stand heavy flooding of the land during the growing period. With a deep water table and a porous soil these crops can be grown while the field is being reclaimed. Sugar beets are likewise resistant, but can not be grown in wet soils. Alfalfa is also quite resistant after a good stand has been secured, but in its younger stages it is a sensitive crop. Wheat and corn are usually classed as sensitive to alkali. Rye and oats are undoubtedly quite resistant, although not as thoroughly tested as some of the crops previously mentioned.

In discussing the resistance of various fruits to alkali it is interesting to quote from Swingle.[a]

> The immense superiority of the date palm over all ordinary crop plants for culture in alkaline lands becomes evident when it is remembered that all ordinary useful plants, such as wheat, corn, and alfalfa, peach, orange, and prune trees, etc., are killed by as much as 0.5 or 0.6 per cent of alkali in the soil, which amount is entirely without influence on the date palm. The more resistant crop plants, such as barley, sorghum, sugar beets, grapevines, olive trees, and possibly pomegranate, jujube, and pistache trees, are able to withstand from 0.6 to 1 per cent of alkali; but these plants are easily injured by an accumulation of the alkali at the surface, which is perfectly harmless to the date palm. About the only crop plant which can withstand considerably over 1 per cent of alkali is the Australian saltbush (*Atriplex semibaccata*), and even this forage plant can not endure nearly as much alkali as the date palm—probably not half as much. As previously noted, asparagus is able to endure much alkali, though the limits of its resistance have not yet been determined. The date palm is, then, the most resistant to alkali of all plants now known capable of commercial culture in arid regions.

The above paragraphs are given to show some of the relations of different agricultural products to alkali, and are not intended to give the exact order found in each locality. This can only be determined after much painstaking study, if indeed it can be determined at all.

RÉSUMÉ OF THE WORK OF THE AGRICULTURAL EXPERIMENT STATIONS ON ALKALI SOILS.

For many years the various experiment stations of the Western States and Territories have been investigating alkali soils and irrigation and drainage waters, and have gathered a valuable store of information on these interesting subjects. This work is summarized below, the States being taken up alphabetically.

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[a] The Date Palm and its Utilization in the Southwestern States, by W. T. Swingle. Bul. 53, Bureau of Plant Industry, U. S. Dept. Agr.

ARIZONA.

In 1898 Forbes[a] described the soils of the Salt River Valley. The valley is described as the most important agricultural district in Arizona, containing about 457 square miles under irrigation. In a general chapter devoted to the nature of the soils the alkali salts are briefly described. The amount of alkali salts which may exist in a soil without injury to vegetation, it is stated, depends on the kind of salts, the character of the soil, and the crops. A large number of samples of virgin soils were collected and chemical analyses made of them. Data were also obtained showing the rate at which water leached through soils, and studies were made of the capillary power of the soils to lift water. In general, it was found that water leached from the sandy soils very rapidly, while it leached from clay soils with exceeding slowness. The capillary motion of water was shown to be correspondingly slow in heavy soils and rapid in sandy soils. Analysis of a soil south of Tempe that supported only a growth of some species of Atriplex (saltbush) and other hardy plants showed upward of 4 per cent of soluble salts, in which sodium chloride largely predominated, with some traces of sodium sulphate and sodium carbonate. This soil was found to be almost impervious to water. Its capacity for holding hygroscopic moisture was likewise considerable, which was attributed to the fact that common salt, or sodium chloride, attracts moisture. After part of the salts had been leached from the soil it lost to a great extent its hygroscopic moisture.

In a chapter on general conditions in the Salt River Valley it is stated that alkali salts are present in excessive amounts in the heavy soils just south and southwest of Tempe. It is pointed out that gypsum can not be used as an antidote, since the soil contains white and not black alkali. Drainage is recommended as the method to be used in reclaiming these lands by the entire removal of the objectionable salts. The Australian saltbush, it is stated, may prove useful on alkali soils on account of the quantity of alkali it can endure.

In 1900 Forbes[b] describes black alkali and white alkali as they occur in Arizona. Black alkali is said to be formed by the decomposition of granite rocks when the rainfall and drainage are not sufficient to carry it away; hence it remains in the soil. In southern Arizona black alkali does not occur in excessive amounts, except where irrigation has caused concentration of the alkali salts. The occasional heavy downpours of rain are said to sweep away large amounts of soluble alkali salts, since it has been observed that the composition of Salt River actually changes in times of flood. The tilth of clay soils is injured more by black alkali than is the tilth of sandy soils, and 0.10 per cent of black alkali in the top 2 feet of soil was found destructive to most crops. Black alkali, besides injuring the tilth of soils, dissolves in the presence of water the humus in the soil and allows of its removal. The worst effect of black alkali is said to be its corrosive action upon the plant at or near the surface of the ground, where it forms a crust in dry weather. When drainage is possible, flooding is advocated to wash the salts down and carry them away in the country drainage.

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[a] Salt River Valley Soils. By R. H. Forbes. Bul. No 28, Ariz. Expt. Sta., 1898.

[b] Timely Hints for Farmers, White Alkali, Black Alkali. By R. H. Forbes. Bul. No. 34, Ariz. Expt. Sta., 1900.

One ton per acre of gypsum is said to be able to overcome 0.036 per cent of black alkali in the surface foot of soil. When clearing land of brush, burning the brush on the roads instead of in the fields is advised, as the ashes contain black alkali.

In a discussion of white alkali consisting of chlorides and sulphates of sodium, calcium, and magnesium, it is stated that these salts result especially from the weathering of volcanic rocks. From 0.10 to 0.50 per cent is considered fatal to most cultivated crops. White alkali also does most of its damage near the surface of the ground. When in solution, it moves with the water until evaporation occurs, when it collects at the surface of the soil. Where evaporation is most rapid, the process of alkali accumulation goes on most rapidly. Hot and windy weather, then, promotes the rise of alkali.

Besides flooding to reclaim alkali land, deep cultivation is also recommended. The alkali crust is buried deeply, and more time is required for it to accumulate again at the surface, while in the meantime a crop may be started that will shade the land and prevent the rise of alkali. Every crop that grows absorbs and removes some of the alkali, so the good effect is permanent. Attention is called to the successful reclamation of alkali fields south of Tempe by this method. Furrow planting is mentioned as another expedient against alkali. The water in the furrow washes the alkali down, the seed then sprouts, and the plants soon become strong enough to withstand more alkali.

In May, 1902, the Arizona station issued, as Bulletin No. 40, a report entitled "A Soil Survey in Salt River Valley." This report embodied the results of cooperative work carried on by this Bureau (then the Division of Soils) and the experiment station. The station bore a share of the expenses of the field work, while Prof. R. H. Forbes furnished many chemical analyses of the alkali soils, crusts, and drainage waters. The results of this work will be included in discussing the work of this Bureau.

In 1902 Forbes[a] described some of the effects of irrigation in connection with the character and composition of the available water supply. Systematic sampling of the Salt, Gila, and Colorado rivers was carried on, and many chemical and physical analyses made of the samples, careful estimates, as well as chemical examinations, being made of the amount of silt carried by the irrigation waters to determine the percentage of fertilizing elements added to the soil. Determinations of the water soluble salts were also made to ascertain the effect of irrigation waters on the alkali question. The salts were found to vary greatly, depending on the height of water in the various rivers. The soluble salts were found to consists mainly of chlorides and sulphates of sodium and calcium. In the Salt and Gila waters during some floods considerable quantities of sodium carbonate were found. It is pointed out that the amount of soluble salts the irrigation waters may carry and not injure the soil depends on the crop grown, the natural drainage of the soil, and the methods of cultivation and irrigation. Where all of these are most favorable a large amount of soluble salts in the irrigating water need not necessarily be feared. On the contrary, land with a scant water supply receiving shallow or insufficient cultivation will in a few years show marked injury from the accumulation of alkali. Abundant flooding is recommended to distribute accumulations of alkali through the soil and carry a part of it into the country drainage. The danger of irrigating in furrows that are seldom if ever disturbed is shown by comparing analyses of soils completely flooded with soils flooded only in the bottom of the furrow. Evaporation from the exposed soil eventually results in the accumulation of alkali along the top of the furrow. Where furrow irrigation is necessary, occasionally leveling the furrows by deep and thorough cultivation is advisable, not only to check the rise of alkali in the soil, but also to economize the water. In the case of such crops as strawberries, which maintain a constant ridge, it is related that in two and a half years a strong crust formed on the ridge, while the bottom of the irrigating furrow was completely free from alkali. In such cases rotation with crops that are completely flooded is strongly urged. The practice of the Pima Indians on the Salt and Gila reservations, who wash out accumulations of alkali by several successive floodings, is quoted. Mention is made of an orange orchard located at Guaymas, Mexico, that was still thriving after twenty-five years' irrigation with water containing considerable alkali. Here the method of irrigation is to throw up embankments about the trees, so that the inclosed space can be flooded 8 or 10 inches deep. This process is repeated at intervals, and the salts are washed down and carried away in the country drainage.

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[a] The River Irrigating Waters of Arizona, their Character and Effects. By R. H. Forbes. Bul. No. 44, Arizona Expt. Sta., 1902.

In subirrigated districts in the Salt River Valley the necessity of drainage ditches is noted in order to insure effective flooding to remove the alkali. The chemical reactions possible in the soils and irrigating waters are shown to be beneficial. The river waters carry an abundance of calcium and magnesium sulphates and chlorides that react with the black alkali or sodium carbonate in the soil, forming lime carbonate and sodium sulphate, both quite harmless when occurring in small quantities.

Careful observations were made of the effects of irrigation on certain soils, and it was found that a large increase of soluble salts, mainly chlorides and sulphates, had taken place. The carbonates found in the soil were kept under control by the beneficial reaction just referred to of the irrigating water carrying an abundance of lime salts, especially sulphates. Furthermore, it was shown that the action of sodium chloride and sodium sulphate is to soften and break up the deposits of lime hardpan, locally called "caliche." This is composed largely of calcium carbonate and is much more soluble in solutions of common salt and sodium sulphate than in pure water. After years of irrigation in the Salt River Valley the hardpan often disappeared, leaving only white granular fragments to mark its former position. In places where the hardpan does not dissolve it is thought to be because the irrigating water contains only slight amounts of sodium chloride.

Observations are also published as to the depth at which various salts concentrated after years of irrigation. In a tree row where evaporation and consequent upward movement of soil water has continued for a long time without interruption the chlorides and sulphates have concentrated at the surface, while sodium carbonate and bicarbonate were found deeper. In the furrow the carbonate and bicarbonate are washed down to the second foot, while the chlorides appear to have been more thoroughly carried away.

CALIFORNIA.

For many years studies of alkali soils and the rise of alkali have been carried on in the State of California. This work was inaugurated by Dr. E. W. Hilgard, professor of agriculture in the University of California. Practically the first publication treating of alkali in the State was in 1877, in Professor Hilgard's report to the president of the university. In this report it is stated that the term "alkali soils" is applied to all soils containing an unusual amount of soluble mineral salts whose presence is frequently made apparent by the efflorescence or "blooming out" on the surface of a white powder or crust soluble in water. Alkali is most apparent in dry weather following rains or irrigation. Later in the season it usually becomes less perceptible from intermixture with dust, as well as from failure of the soil water to rise near enough to the surface. The first rain water, dissolving the salty substances, carries them partly into the water courses, but chiefly back into the soil, whence they rise again at the recurrence of dry weather.

The immediate source of alkali, it is stated, is usually found in the soil water, which, rising from below and evaporating at the surface, deposits there whatever of dissolved matter it may contain. Such water is by no means always perceptibly salty or alkaline. The soil, acting like a wick, draws up the soil water and allows it to evaporate at the surface, where all of the dissolved salts accumulate until the soil becomes so impregnated as to injure or kill all useful vegetation. The injury will be found to be most severe just at or near the crown of the root, where the stem emerges from the soil.

The most obvious remedy for alkali is the leaching out of the salts by flooding, accompanied, if possible, by underdraining, a method habitually resorted to in the seacoast marshes near the mouths of rivers. When the water table is a few feet from the surface and contains much saline matter, or when the subsoil contains much saline matter, several remedies are proposed.

1. When the alkali is neither abundant nor noxious, frequent and deep tillage may afford all the relief needed.

2. Underdrains may lower the water table from which the saline matters are derived and may so favor the washing out of the salts during the rainy season that with deep tillage no more injurious accumulations will take place.

3. When the quantity of salt or alkali is small but is very injurious or corrosive, the application of chemical antidotes may mitigate the evil or sometimes completely relieve it. In this case it is necessary to determine by analysis the nature of the alkali.

The salts determined up to the year 1877 were:

(*a*) Neutral alkali salts, such as common salt, Glauber's salt, sulphate of potassium, etc. When present in large quantities relief can only be obtained by washing them out of the soil.

(*b*) Soluble earthy and metallic sulphates and chlorides, as Epsom salt, bittern, chloride of calcium, alum, copperas, etc. For a cheap and efficient antidote lime is recommended, and in some cases a calcareous marl is said to answer the purpose.

(*c*) Alkaline carbonates and borates. The carbonates are very injurious, even in the smallest amounts. The antidote for these salts is said to be gypsum or land plaster. These chemical antidotes should be sown or spread on the surface and plowed or harrowed in to a moderate depth just prior to irrigation. The gypsum should be put in with the grain.

An analysis of soil from Sherman Island, Sacramento County, showed the salts to consist of sulphate of magnesia, sodium chloride, and potassium chloride. Alkali soil from near Corvallis, Los Angeles County, contained sodium sulphate, sodium chloride, and sodium carbonate as the principal ingredients. The quantity of the last named is sufficient to dissolve not only dead vegetable matter but also to attack and destroy living rootlets and bark when accumulated by surface evaporation. Soil from a seacoast flat near Anaheim, in Los Angeles County, contained largely sodium chloride and calcium sulphate (gypsum), with small amounts of potassium salts, magnesium sulphates, and alkaline nitrates. These salts are substantially the materials contained in sea water.

A sample of alkali soil from Westminster Colony, Los Angeles County, contained 0.54 per cent of soluble salts, of which sodium carbonate was the principal ingredient, with small amounts of potassium sulphate, sodium chloride, and potassium carbonate. This sample was representative of certain parts of a tract of 30,000 acres. It was considered too strong for barley, but it was found that sugar beets would grow under favorable circumstances. An experiment was tried on 0.1 of an acre, applying 65 pounds of gypsum, plowing it under about 6 inches deep, and then 35 pounds of gypsum were sowed. The land was then harrowed and planted with corn. Where water stood on the surface of the soil there was a good stand of corn, but where the land was subirrigated not more than half a stand of corn was realized. The failure was ascribed to the fact that the gypsum did not come in contact with the water.

An analysis of a crust of an alkali soil from near San Jose, in Santa Clara County, showed principally sodium sulphate, sodium carbonate, and sodium chloride. The most successful attempts at cultivation of this soil have been by deep ditch drainage, copious washings by flooding, and fine surface cultivation to prevent the alkali from rising to the surface.

In 1879 Hilgard[a] reports further studies of alkali soils. Samples of soil near Stockton, San Joaquin County, were analyzed and found to contain sodium carbonate as the principal ingredient, as well as sodium sulphate and sodium chloride. Other samples from near-by localities contained the same salts, but in different proportions; in one the sulphates largely predominated, while another sample consisted almost wholly of sodium carbonate. One sample, which to a depth of 12 inches contained about 1 per cent of salts, carried largely sodium carbonate, sodium nitrate, bisodic-hydric phosphate, and lesser quantities of sodium sulphate and sodium chloride.

Alkali soil from Hueneme, Ventura County, contained sodium sulphate, magnesium sulphate, and sodium chloride as the principal ingredients. The alkali in the soil near Collinsville, Solano County, consisted of magnesium sulphate, sodium sulphate, and sodium chloride. Soil from the Emigrant Ditch region, Fresno County, consisted almost wholly of sodium carbonate, with a little sodium chloride.

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[a] E. W. Hilgard. Supplement to the Biennial Report of the Board of Regents, College of Agriculture, University of California, 1879.

Alkali soils from near Lemore, Tulare County, were found to contain as the principal salts chiefly sodium sulphate and magnesium sulphate.

In 1880 Hilgard[a] notes that, roughly speaking, there is in the State an obvious inverse relation between the rainfall and the prevalence of alkali in the soils. In the region about Sacramento the more copious rainfall seems to keep soils leached of their alkali. The general increase of alkali on irrigated lands is noted in the upper parts of the San Joaquin Valley, especially in the counties of Kern, Tulare, and Fresno south of Kings River. It is pointed out that the term "rise of alkali" is accurate, since it is emphatically true that alkali salts rise from below through the agency of water evaporating at the surface. Irrigation has not only increased the amount of water evaporating from the surface, but has also caused a much greater depth of subsoil to be drawn upon for its alkali. Each succeeding irrigation followed by evaporation tends to accumulate the salts nearer the surface, so that finally the root crowns of the crops are burnt up before even beginning to head. To prevent the alkali from accumulating at the surface, attention is called to the crust that forms, especially in clayey soils, and to the fact that means should be taken to keep this broken, thereby reducing surface evaporation. Hoed crops, which require the surface to be frequently cultivated, and alfalfa, which heavily shades the surface, are strongly recommended. Of the hoed crops, cotton, hemp, jute, and ramie are suggested among the textile crops, and beets, carrots, turnips, sweet potatoes, etc., among the root crops. Large and small fruits, especially grapes and prunes, and sorghum and sugar cane are also suggested. Cereal crops requiring broadcast culture are regarded as a poor selection for an alkali region, since such crops allow of rapid surface evaporation, with its consequent increase of the alkali content at the surface.

Subirrigation is recommended instead of surface irrigation, since the former method reduces the surface evaporation, as well as reduces the amount of water necessary. The expense of a suitable system of subirrigation pipes is brought out, but it is emphasized that the same pipes could also be used for drainage when flooding the land to leach out the injurious accumulations already formed at the surface. In a study of some of the river waters and those of Tulare Lake to determine their possible effect on the alkali condition, the waters of Tulare Lake were found to be especially harmful and to be growing worse from year to year, until the rivers leading from it all contained slight traces of alkali, plainly showing that some precautions should be taken in the use of their waters.

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[a] E. W. Hilgard. Report of the Professor in Charge to the Board of Regents, College of Agriculture, University of California, 1880.

In 1882 Hilgard[a] pointed out that, while the corrosive action exerted by alkali salts upon the upper roots or root crowns of crops is the most serious and common source of injury, when the alkali is carbonate of soda or potash there is still another effect, especially on the heavier class of soils. This is the difficulty of producing a condition of good tilth, owing to the tendency of alkali solutions to maintain all true clays in a tamped condition. The alkaline carbonates, moreover, dissolve the humus which imparts the dark color to the water standing on the alkali spots, giving rise to the name "black alkali."

In 1886 Hilgard[b] published the analyses of several river waters and discussed their composition. The water of the Los Angeles River contains no carbonate of soda, but only mineral and earthy salts; hence the accumulation of alkali salts will only occur when its waters are more closely utilized and relatively scarcer. Kern River contains the same dissolved salts as Tulare Lake, but the proportion is 1 to 22. This river contains carbonates, as well as less injurious salts. Kings River is shown by analyses to be quite free from carbonates, but contains other soluble salts. The San Joaquin River contains some carbonates, but not so much as Kern River. From the irrigator's standpoint the waters of Mokelumne River are the best, with Kings River next. Then comes the Merced, and after it the Sacramento, and then the San Joaquin, followed by Kern River, and last of all Tulare Lake.

In 1889 Doctor Hilgard,[c] speaking of the kinds of alkali, stated that the distinction between "black alkali" and "white alkali" is important. In black alkali sodium carbonate predominates, while white alkali consists mainly of the bland and relatively innocuous Glauber's and common salt. Black alkali is many times more injurious than white alkali, not only because it directly corrodes the root crowns of plants, but also because it dissolves out the important ingredients of humus, and renders the heavier clay soils almost untillable. This latter effect is even noticed on sandy soils, which often bake badly. With white alkali accumulated at the surface the soils can be easily tilled, and only when it accumulates in excessive quantities does it injure surface roots and root crowns. Underdrainage is recommended as the general and absolute corrective of alkali. Simply putting water on the surface will not suffice unless its removal after passing through the soil is provided for. If the alkali solution descends no farther than the subsoil and remains there, it will again ascend to the surface after evaporation has commenced, and thus no permanent good is accomplished. The value of this method has been tested in California and India, and it was found that the alkali actually increased instead of decreased. To flood the land until underdrains, laid a reasonable distance apart, have run for some time will end the trouble, not only for the time being, but for centuries, unless, of course, solid beds of alkali salts underlie the soils, as seems to be the case in some of the lower lands of the Tulare Lake region. The presence of calcareous hardpan below the surface may make this process more difficult, but it can be broken in many places and the ditches dug deeper than the hardpan. Doctor Hilgard states, in further discussing the underdrainage of land, that the time is not far distant when in California the laying of underdrains will be considered an excellent investment on any land as valuable as all irrigated land is likely to be, and when that day comes "alkali" will no longer be found in irrigated lands.

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[a] E. W. Hilgard. Report on the Climatic and Agricultural Features and the Agricultural Practices and Needs of the Arid Regions of the Pacific Slope. Departmental Report No. 20 of the U. S. Commissioner of Agriculture, 1882.

[b] E. W. Hilgard. Alkali Lands, Irrigation and Drainage in their Mutual Relation. Appendix No. VII, Annual Report, 1886. Univ. of California, 1886.

[c] E. W. Hilgard. Rise of Alkali in the San Joaquin Valley. Bul. No. 83, California Expt. Sta., 1889.

Hilgard mentions, as an example of the variability of the composition of the soluble salts within short distances, the case of a 10-acre tract near Fresno on which both white and black alkali occur. In Tulare County carbonate of soda is quite generally present in large proportion, doubtless in consequence of the more general prevalence of heavy soils rich in vegetable matter, which promotes the formation of carbonate.

In 1892 Hilgard[a] discussed the influence of climatic conditions upon the chemical processes in soils. In arid regions the easily soluble alkali salts, notably those of sodium and to some extent potassium, with certain easily soluble earthy compounds—sulphates and chlorides of calcium and magnesium—are retained in the soil to a greater or less extent. This is directly due to insufficient rainfall to leach away these substances.

He points out that alkali lands are a characteristic feature of all regions of scanty rainfall and are found in all continents—in Europe in a portion of the Hungarian lowlands and in a few localities of Mediterranean Spain. Even in humid regions limited areas occur where various kinds of salts may be found. In arid regions the alkali salts are not only retained in their first soluble form, but by their continued presence profoundly influence the processes of soil formation. With an annual rainfall of 20 inches or more the retention of any considerable amount of soluble salts in the soil becomes impossible under ordinary conditions of soil and drainage. Below that limit of rainfall the degree of alkalinity is dependent more or less upon local conditions, as well as upon soil texture.

In India, Hilgard states, we find a large area in which alkali (reh) is more or less troublesome. This area extends all the way from the

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[a] Relations of Soils to Climate. By E. W. Hilgard. Bul. No. 3, Weather Bureau, U. S. Dept. of Agr.

Indus and the Arabian Sea on the west to a little beyond the Ganges on the east and from the Gulf of Cutch on the south to Afghanistan on the north, including all of Sind, Rajputana, the plains of the Punjab, the Northwest Provinces, and part of Oudh to within a short distance of the Himalaya ranges, including Lahore. Within this region the rainfall varies from a minimum of 4.3 inches at Jacobabad on the Afghan frontier beyond the Indus to over 30 inches at Cawnpoor on the Ganges. We have but scanty data as to the area of land affected by injurious accumulations of alkali salts, but all the provinces mentioned above are reported as suffering more or less from "reh." The country surrounding the cities of Delhi, Meerat, Agra, and Cawnpoor suffers a great deal. As all this country receives between 20 and 30 inches of rainfall, it is probably the distribution of the rainfall that allows the accumulation of alkali. The conditions giving rise to the alkali are quite similar to those in North America. The calcareous nature of the rocks and their tendency to form "kankar" or hardpan is pointed out. The composition of the alkali is similar to that of other countries. Much stress is laid upon the occurrence of nitrates, and nitrate of lime is mentioned as a possible antidote for carbonate of soda.

A state of affairs quite analogous to the arid West of America exists in Egypt, Arabia, Syria, and Persia, as well as in the Aralo-Caspian plains. Saline efflorescences are mentioned as obstacles to cultivation, while the shallow wells are so salty as to be almost unfit for domestic uses. The "shotts" on the northern edge of the African desert in the French colonies are regarded as hopeless alkali sinks.

The following table shows the composition of the soluble alkali in foreign localities:

Composition of the soluble alkali in foreign countries.

Region.	Potassium sulphate (K_2SO_4).	Sodium sulphate (Na_2SO_4).	Sodium carbonate (Na_2CO_3).	Sodium chloride ($NaCl$).	Sodium phosphate (Na_3PO_4).	Magnesium sulphate ($MgSO_4$).	Magnesium chloride ($MgCl_2$).	Total.
Europe:								
Hungarian plain—	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Kalocsa		0.2	48.1	51.7				100.0
Debreczin		1.6	92.5	4.4	1.5			100.0
Asia:								
Plain of the Araxes		10.4	14.7	74.6				99.7
		18.2	12.1	69.7				100.0
		15.5	69.0	15.5				100.0
Aden			67.2	32.8				100.0
India	11.1	7.0	79.0	2.9				100.0
Africa:								
Egypt		23.6	28.2	48.2				100.0
		38.3	47.7	14.0				100.0
Fezzan		.6	98.7	.7				100.0
Australia:								
Bendigo	1.28	40.05		47.47		11.20		100.0
	1.63			81.88		9.86	6.73	100.10

In this same bulletin Hilgard discusses the effect of irrigation on alkali soils. Since the occurrence of soluble salts in soils is due to the deficient rainfall and consequent failure to leach out soluble matters, it seems reasonable to expect that when the soils are irrigated the normal leaching process would soon free the soil from any excess of soluble salts. But just the opposite is true, and the reason is that the quantity and distribution of irrigation water are different from the rainfall of humid regions. Usually the total quantity of irrigation water used during the year is less than the annual rainfall of humid sections, a great abundance being used for but a short time. The irrigation water carries the alkali down with it; but as the water does not reach the country drainage when evaporation begins, it reascends, and finally, if the whole of the water evaporates, all of the alkali is left on or close to the surface. As irrigation water usually penetrates deeper than the rains, it follows that a larger quantity of alkali is carried to the surface than was there before.

In considering the reclamation of alkali land by underdrainage and flooding, it is urged that such a method is expensive, and, moreover, washes valuable plant food from the soil. Other possible remedies are suggested, as checking surface evaporation by means of deep and thorough cultivation. The use of gypsum is earnestly urged as a corrective of black alkali, as it neutralizes the sodium carbonate by forming sodium sulphate or white alkali.

Hilgard and Jaffa[a] point out the greater nitrogen content of the humus of arid soils as compared with humid soils. They are led to conclude that the alkali carbonate does not prevent the accumulation of nitrogen in humus, while under the influence of the hot sun free or carbonated ammonia is given off. Under these conditions nitrification must be greatly favored, provided the nitric ferment is not prevented by an injurious excess of the alkaline carbonate from exerting its action.

Loughridge[b] states that the presence of alkali salts in a soil produces a puddling or deflocculation of the particles when wet and a consequent compact condition which prevents the rapid rise of water. This puddling is accompanied by a large contraction of volume, a feature which to a far less degree has been observed in other soils.

Hilgard,[c] in a paper on the distribution of the salts in alkali soils, points out the great productiveness of arid soils when first irrigated, but shows that small alkali spots may appear in the course of a few years, and that, even where the irrigation water is very pure, the trouble from alkali may increase just the same.

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[a] E. W. Hilgard and M. E. Jaffa. Proceedings of the Society for the Promotion of Agricultural Science, 1890.

[b] The Capillary Rise of Water in Soils. By R. H. Loughridge. Report of the Agricultural Experiment Stations of the Univ. of California, 1893–94.

[c] E. W. Hilgard. Annual Report California Expt. Sta., 1895.

From studies carried on it was found that the main mass of the alkali salts exists in the soil and subsoil within a short distance of the surface, while chemical examination showed the alkali to consist of such compounds as are known to exist in all soils in consequence of weathering and that it contains all the ingredients useful, as well as those useless, to plant growth. He concludes that the amount of salts in alkali lands is limited and that if once removed or rendered innocuous it will take thousands of years in the future, as in the past, before another such supply can originate from the very gradual weathering of the soil mass. The rainfall in arid countries washes the soluble salts to a short distance below the surface, seldom below 3 feet, and from this depth they may partially or wholly reascend with the soil moisture and be deposited on or near the surface by evaporation during the dry season. At the lower limit of the penetration of rainfall a gradual accumulation of the saline matter probably takes place. Early in May such soils may be covered with wild flowers, as the alkali has been washed down, and the roots only penetrate to a slight depth and are not damaged by the deeper accumulation of alkali. The surface of the land being shaded and the soil moisture escaping through the plants, evaporation from the surface of the soil is restricted, and the accumulation of alkali at the surface is reduced to a minimum. A crop like alfalfa will tend to diminish or prevent the rise of alkali. Such crops may flourish for years on a soil that, if left bare during the dry season for the sowing of a fall crop, may prove altogether too alkaline near the surface and kill the crop.

Seepage water from overirrigation, or leaky irrigation ditches, by filling up the land below the alkali-impregnated hardpan, dissolves the salts and carries them to the surface. Evaporation from the moistened surface, which is going on more or less throughout the year, causes the salts to accumulate slowly at or near the surface, until the maximum amount is found there instead of 3 feet below. Surface irrigation produces the same result, since water is usually not supplied in sufficient quantities to leach out the salts, nearly all the water supplied evaporating at the surface. The irrigation water penetrates the soil to a greater depth than the rain water. Hence the salts are dissolved and carried upward from a greater depth. Any course of procedure, then, that diminishes evaporation at the surface tends to prevent the rise of alkali. Mulching and shading both produce this effect.

Hilgard[a] states that even in very pervious soils the leaching out of white alkali is greatly accelerated by laying underdrains. In the case of black alkali, he points out that either an impervious hardpan or the impenetrability of the surface soil itself will render underdrains ineffective unless the sodium carbonate, with its compacting effects on the soil, is first destroyed by the use of gypsum. This is not only necessary in order to render drainage and leaching possible, but is also advisable to prevent the leaching out of valuable humus and soluble phosphates which are rendered insoluble by the action of the gypsum, though not made unavailable to plants. Since alkali lands are very productive when reclaimed, it is advisable to attempt their reclamation, even though this may be somewhat expensive.

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[a] Origin, Value, and Reclamation of Alkali Lands. By E. W. Hilgard. Yearbook, U. S. Dept. of Agr., 1895.

Hilgard and Loughridge[a] show that on one and the same soil the lower and moister ground shows more of black alkali or sodium carbonate than the higher, and that as between heavy or clay soils and light or sandy soils in similar locations the sandy soil invariably shows less black alkali than the denser clay soil. Generally speaking, black alkali occurs mostly in relatively low or badly drained ground, and the white alkali on high or well-drained ground. The important practical conclusion to be drawn from this fact is that whenever land is thoroughly aerated—as by underdrainage—there is little danger from black alkali, and, even if temporarily formed, it will soon vanish by transformation into the white or neutral salts. Whenever, on the contrary, alkali land is allowed to become water-soaked for any length of time the neutral or white salts may be transformed into the corrosive carbonate. It is well known from experience, however, that a soil containing much gypsum is very liable to be seriously damaged by water-logging, because of the "reduction" of the sulphates to sulphides, resulting in the production of sulphuretted hydrogen—the gas of rotten eggs—which is so fatal to vegetation.

Loughridge,[b] treating of the effects of gypsum on black alkali lands, concludes, first, that the amount of gypsum to be applied to alkali soils must be about double that of the carbonate of soda present; second, that the effect is then apparent within two or three days, and third, that the effect is probably permanent in the conversion of the carbonate into the sulphate. When an excess of gypsum is used it can do no damage to the soil unless the soil should become water-logged.

Loughridge[c] states that the effect of alkali is both direct and indirect, being direct in its action upon the trees through their roots and indirect in its action upon the physical nature of the soil, and hence upon the tree. The direct action varies with the nature of the alkali and with the quantity in the soil. Carbonate of soda is the most dangerous, because of its corrosive action on the rootlets of plants and trees.

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[a] The Distribution of the Salts in Alkali Soils. By E. W. Hilgard and R. H. Loughridge. Bul. No. 108, California Expt. Sta., 1895.

[b] R. H. Loughridge. Annual Report, California Expt. Sta., 1896–97.

[c] R. H. Loughridge. Annual Report, California Expt. Sta., 1897–98

In the Corona orchards only 960 pounds of carbonate per acre in 3 feet of soil undoubtedly caused the falling of leaves and fruit.

The chief injurious effect of sodium chloride upon plant life is that of an antiseptic whose action seems to be to arrest the development of or to kill the nitrifying organisms in the soil. Sodium sulphate is injurious in large amounts, and as it is a neutral salt its action would seem to be chiefly that of preventing osmosis of the soil solution into the cells of the roots, thus depriving the plant or the tree of sufficient nourishment for the maintenance of growth, and finally producing death.

Doctor Hilgard, discussing in the same report the use of saline and alkali waters in irrigation, states that we can apply to a fairly pervious soil an amount of saline irrigation water large enough to wash into the subdrainage any former accumulations, and when this operation is repeated at intervals not too far apart and surface evaporation is not allowed to progress to too great an extent, relatively strong saline water may be used with impunity, the plants then growing substantially under the same conditions as the luxuriant vegetation so commonly found on the margins of alkali lakes. If, however, the same water were used according to the ordinary practice of irrigators, trouble would undoubtedly arise, since the repeated shallow wettings, with subsequent evaporation, would accumulate the alkali at or near the surface.

Loughridge[a] gives the results of a number of years' observation and study on the resistance of plants to alkali. These observations were carried on at the University of California substation in southern California and at the Tulare substation in the San Joaquin Valley. He points out the conditions that may affect the interpretation of the results of alkali examinations and lead to erroneous conclusions with regard to the effect of alkali on cultures. These are climate, the possible presence of insects or diseases, and imperfect physical conditions in the soil and subsoil—such as hardpan, high water table, shallowness of soil, lack of ventilation and aeration, poor moisture supply, etc.—any of which might cause injury to the plant. All of these must be considered before the trouble can be charged to alkali. The complexity and variability of the salts still further confuses the problem.

Chemical analyses of a large number of soils were made to determine the tolerance of various crops and fruits. Some of the results are as follows:

Almonds.—The exact point of tolerance was not ascertained, but it was clearly shown that 2,000 pounds of sodium carbonate and 3,000 pounds of sodium chloride per acre to a depth of 4 feet affected the growth.

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[a] Tolerance of Alkali by Various Cultures. Bul. No. 133, California Expt. Sta., 1901.

Apples.—At the Tulare substation this tree was found to be quite resistant to alkali. The examinations showed that the apple will tolerate the presence of 14,000 pounds of sulphates, 650 pounds of sodium carbonate, and 1,200 pounds of sodium chloride. It is injured by 1,200 pounds of carbonate and 3,000 pounds of sodium chloride per acre to a depth of 4 feet.

Figs.—This tree easily tolerated 25,000 pounds of sodium sulphate and 1,100 pounds of sodium carbonate per acre in 4 feet.

Lemons.—This seems the least tolerant of all the fruit trees, for its growth was stunted by only 1,440 pounds of sodium chloride per acre to a depth of 4 feet, and was killed by 1,900 pounds combined with 1,900 pounds of carbonate of soda. Its endurance of carbonate of soda alone was not ascertained.

Oranges.—At the Tulare substation oranges seemed to do well in the presence of 3,840 pounds of carbonate and 3,360 pounds of sodium chloride per acre to a depth of 4 feet.

Olives.—The olive tree was shown to be immune to as much as 3,000 pounds of sodium carbonate and 30,000 pounds of sodium sulphate per acre to a depth of 4 feet, and the limit of tolerance will probably be found to be much above these figures. The tolerance for common salt is above 6,000 pounds per acre in the first 4 feet.

Peaches.—At Tulare it seemed probable that the limits of alkali tolerated by peach trees may be placed at 10,000 pounds of sulphates, 750 pounds of carbonate, and 1,200 pounds of sodium chloride per acre in the first 4 feet.

Pears.—The results seem to show that while the pear can tolerate as much as 1,400 pounds of sodium chloride and 1,800 pounds of carbonate per acre to a depth of 4 feet, it is seriously affected by 38,000 pounds of sodium sulphate.

Plums.—At Tulare the plum was found to be one of the most sensitive of trees to the effects of alkali salts.

Prunes.—This tree can stand large quantities of sodium chloride, at least.

Wheat.—From the results obtained it appears that wheat should do well in deep and loose soils having not more than 20,000 pounds of total alkali, if there is not more than 1,200 pounds each of sodium carbonate and sodium chloride per acre to a depth of 4 feet.

Barley.—This plant is more resistant to alkali than wheat, but was killed by 18,720 pounds of sodium carbonate.

Alfalfa.—When young, alfalfa roots are very tender and sensitive to the corrosive action of carbonate of soda, and as they are confined to the upper foot or two of the soil, they are fully within the reach of this salt. When the roots are older and have penetrated deep into the soil, the root crown has become more corky and hardened and less sensitive, so that it is able to withstand a far greater quantity of alkali. While alfalfa is easily killed by alkali when young, it will tolerate as much as 6,000 pounds of sodium chloride, 3,000 pounds of carbonate, and 102,000 pounds of sulphate per acre in the first 6 feet of soil, if it succeeds in getting a good start. It is therefore necessary, in order to get a start, that the top soil be comparatively free from alkali salts.

Saltbush.—The Argentine saltbush grew luxuriantly in soil that carried 14,600 pounds of sodium carbonate. The Australian saltbush can tolerate 156,720 pounds of salts per acre in the first 4 feet.

Sorghum.—This can easily tolerate as much as 10,000 pounds of sodium carbonate, the same amount of sodium chloride, and 75,000 pounds of sulphate of soda. It is therefore one of the most resistant of the plants tested.

Sugar beets.—The maximum of each salt tolerated by this plant in two thickly sown plats was 52,000 pounds of sulphates, 4,000 pounds of carbonate, and 5,400 pounds of sodium chloride.

Celery.—This plant will easily tolerate as much as 10,000 pounds of sodium chloride, but is killed by 30,000 pounds per acre.

Onions.—This crop grew well on land with 400 pounds of sodium chloride in the surface foot and 4,000 pounds of sulphate per acre.

Potatoes.—Near Bakersfield, potatoes grew on black alluvial soil which held in the first foot 18,400 pounds of alkali, of which 4,000 pounds was sodium carbonate and 6,800 pounds sodium chloride.

In the following table are given the results obtained:

Highest quantity of alkali salts to a depth of 4 feet by which fruit trees and various crops were found unaffected—arranged from the highest to the lowest.

[Pounds per acre in 4 feet depth.]

FRUIT TREES.

Sulphates (Glauber's salt).	Pounds.	Carbonate (sal soda).	Pounds.
Grapes	40,800	Grapes	7,550
Olives	30,640	Oranges	3,840
Figs	24,480	Olives	2,880
Almonds	22,720	Pears	1,760
Oranges	18,600	Almonds	1,440
Pears	17,800	Prunes	1,360
Apples	14,240	Figs	1,120
Peaches	9,600	Peaches	680
Prunes	9,240	Apples	640
Apricots	8,640	Apricots	480
Lemons	4,480	Lemons	480
Mulberry	3,360	Mulberry	160

Chloride (common salt).	Pounds.	Total alkali.	Pounds.
Grapes	9,640	Grapes	45,760
Olives	6,640	Olives	40,160
Oranges	3,360	Almonds	26,560
Almonds	2,400	Figs	26,400
Mulberry	2,240	Oranges	21,840
Pears	1,360	Pears	20,920
Apples	1,240	Apples	16,120
Prunes	1,200	Prunes	11,800
Peaches	1,000	Peaches	11,280
Apricots	960	Apricots	10,080
Lemons	800	Lemons	5,760
Figs	800	Mulberry	5,760

Highest quantity of alkali salts to a depth of 4 feet by which fruit trees and various crops were found unaffected—arranged from the highest to the lowest—Continued.

SMALL CULTURES.

Sulphates (Glauber's salt).	Pounds.	Carbonate (sal soda).	Pounds.
Saltbush	125,640	Saltbush	18,560
Alfalfa (old)	102,480	Barley	12,170
Alfalfa (young)	11,120	Bur clover	11,300
Hairy vetch	63,720	Sorghum	9.840
Sorghum	61,840	Radish	8.720
Sugar beet	52,640	Modiola	4,760
Sunflower	52,640	Sugar beet	4,000
Radish	51,880	Gluten wheat	3,000
Artichoke	38,720	Artichoke	2,760
Carrot	24,880	Lupin	2,720
Gluten wheat	20,960	Hairy vetch	2,480
Wheat	15,120	Alfalfa	2,360
Barley	12,020	Grasses	2,300
Goat's rue	10,880	Kafir corn	1,800
Rye	9,800	Sweet corn	1,800
Cañaigre	9,160	Sunflower	1,760
Ray grass	6,920	Wheat	1,480
Modiola	6,800	Carrot	1,240
Bur clover	5,700	Rye	960
Lupin	5,440	Goat's rue	760
White melilot	4,920	White melilot	480
Celery	4,080	Cañaigre	120

Chloride (common salt).	Pounds.	Total alkali.	Pounds.
Modiola	40,860	Saltbush	156,720
Saltbush	12,520	Alfalfa (old)	110,320
Sorghum	9,680	Alfalfa (young)	13,120
Celery	9,600	Sorghum	81,360
Alfalfa (old)	5,760	Hairy vetch	69,360
Alfalfa (young)	760	Radish	62,840
Sunflower	5,440	Sunflower	59,840
Sugar beet	5,440	Sugar beet	59,840
Barley	5,100	Modiola	52,420
Hairy vetch	3,160	Artichoke	42,960
Lupin	3,040	Carrot	28,480
Carrot	2,360	Barley	25,520
Radish	2,240	Gluten wheat	24.320
Rye	1,720	Wheat	17,280
Artichoke	1,480	Bur clover	17,000
Gluten wheat	1,480	Celery	13,680
Wheat	1,160	Rye	12,480
Grasses	1,000	Goat's rue	11,800
White melilot	440	Lupin	11,200
Goat's rue	160	Cañaigre	9,360
Cañaigre	80	Ray grass	6.920
		White melilot	5,840

The general results from the above observations are that grapes and olives stand at the head among the fruits in their tolerance of each of the alkali salts. The quantity tolerated depends largely upon the distribution of the several salts in the vertical soil column, the injury done by the alkali being most severe in the surface foot, where the feeding rootlets are usually found. Methods of culture and irrigation are recommended that will encourage deep rooting on the part of crops. The quantity tolerated also varies with different varieties of the same plant. The quantity tolerated by different plants likewise varies with the nature of the soil, being lowest in heavy clay and fine-grained soils in which the downward growth of plant roots is restricted, and highest in loam and sandy soils in which the roots have greater freedom of penetration.

Some plants, such as saltbush and alfalfa, are quite susceptible to alkali when young, but when the roots penetrate deeply and the ground is heavily covered with the foliage of the plant they are largely immune.

In a report[a] on the lands of the Colorado Delta, in the Salton Basin, the classes of alkali contained in the soils are discussed and recommendations given for the treatment of the soils. Many samples of soil were collected and analyses made of them. The content of alkali salts was found to vary greatly within short distances. It is pointed out that sooner or later there will arise the necessity of drainage canals to keep the seepage water from swamping the lower land. With this underflow of water there is greater or less accumulation of alkali salts in the lower areas, which, taken in connection with the naturally high lime content of the soil, is almost sure to result in the formation of considerable black alkali, a condition which could even then be seen in a few localities.

In considering only the quantity of alkali salts in the soils of this region it was found that the outlook was not altogether encouraging. While there was some land not too strongly impregnated to produce, without any special precautions, good crops of cereals, especially barley and alfalfa, there was a very large proportion of the land so strongly charged that, without due care, crops could be secured only for two or three years and in some cases none at all. In the great majority of cases there was a great predominance of sulphates. Carbonate of soda was found to be quite subordinate because of the presence of gypsum throughout the valley. Sodium chloride was rather abundant near the surface.

Shinn,[b] in the annual report for 1898–1901, gives the results of the alkali reclamation work at the Tulare substation. The solution of the alkali problem, as set forth in previous publications, is stated as follows: Control of irrigation, control of drainage, study of the extremely varying kinds and degrees of alkali, and use but not waste of gypsum to neutralize carbonates.

An experimental tract of 20 acres of alkali land was selected surrounded by land strongly impregnated with alkali. This sloped irregularly from northeast to southwest, and was traversed by old slough channels. The alkali consisted largely of carbonates, and gypsum was used to neutralize the carbonate to the relatively innocuous sulphate. Charts accompany the report to show the progress made in the reclamation. Work was started in 1889, and the soil at once showed the effects of the application of gypsum. In 1893, however, partly reclaimed land showed the beginning of a rise of alkali due to the wet seasons, and the gradual amelioration of the worst areas by cultivation and the use of gypsum. In 1896 the charts showed increase of alkali and loss to cultivation of much of the land that had been reclaimed, due doubtless to increased irrigation of surrounding lands. After this serious rise of alkali in 1896 a second drainage pit was cut through to gravel and a deep ditch was dug to intercept the flow of water from the north side, and more gypsum was applied. The alkali yielded to this treatment, the accumulation of alkali was prevented, and crops were harvested on much of the land that originally could not be cropped at all.

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[a] Lands of the Colorado Delta in the Salton Basin. By E. W. Hilgard, F. J. Shaw, and G. W. Shaw. Bul. No. 140, California Expt. Sta., 1902.

[b] C. H. Shinn. Alkali Reclamation at Tulare Substation. Report of California Expt. Sta. for 1898–1901.

In 1889, 3 tons of gypsum were applied to the entire 20 acres. Since 1891, 100 tons of gypsum have been used, making an average of 7.7 tons per acre for thirteen years. Allowing for impurities, however, an average of not more than 5.39 tons per acre were applied each year. Some of the land still remained in bad condition in 1902.

The plans for the reclamation of alkali lands recommended by Loughridge[a] in the report for 1901–1903, are—

(1) The application of gypsum if black alkali be present, in order to insure the percolation of the irrigation water. The gypsum should be applied in sufficient quantities to neutralize the carbonate and convert it into the sulphate.

(2) If possible, the establishment of a system of subdrainage with tiles placed at a depth of 4 to 7 feet, according to the character of the soil and the crops intended to be grown.

(3) The application of sufficient water by flooding to percolate down through the soil to the drains and thus carry off the soluble alkali salts.

(4) Should drainage of the land not be feasible, then the alkali should be leached down to a depth of 6 feet by flooding the field with water. Care should be taken to keep the surface soil loose to a depth of at least 3 inches, in order to prevent the subsequent rise of the water and the return of the alkali to the surface.

Hilgard, with Weber,[b] and later with Jaffa,[c] studied the effect of carbon dioxide on soil solutions and drainage waters. From long observations Hilgard was impressed by the very great frequency of the occurrence of gypsum in alkali waters and soil leachings, even when considerable quantities of soluble alkaline carbonates were present and when, a priori, the precipitation of practically all of the calcium in the gypsum as insoluble calcium carbonate might be expected.

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[a] R. H. Loughridge. Annual Report, California Expt. Sta., 1901–1903.

[b] E. W. Hilgard and A. H. Weber. On the Mutual Reaction of Carbonates, Sulphates, and Chlorides of the Alkaline Earths and Alkalies. Proceedings of the Society for the Promotion of Agricultural Science, 1888.

[c] E. W. Hilgard and M. E. Jaffa. Further Experiments on the Reaction Between Alkaline Sulphates, Calcic Carbonates, and Free Carbonic Acid. Proceedings of the Society for the Promotion of Agricultural Science, 1890.

Solutions containing gypsum, or in contact with it, are always alkaline, but on being evaporated to dryness or to relatively high concentration this alkalinity is diminished and a greater or less amount of calcium is precipitated as ordinary carbonate.

Considering the origin of these solutions, Hilgard is led to the view that the unlooked-for phenomena presented are due to the presence of an excess of carbonic acid in the waters or soil leachings, and points out the great probability of its presence. This was tested by passing carbon dioxide for periods of time varying from ten minutes to two hours into solutions of alkali sulphates and chlorides, at the ordinary room temperature, in which precipitated calcium carbonate was suspended. Taking care to avoid the first masking of the reaction, which sometimes occurred from the excess of carbon dioxide, in all cases the solutions were found to have become alkaline, and on the addition of alcohol to the solution a precipitate was thrown down in which gypsum and calcium carbonate could both be readily recognized.

Together with Weber, he then undertook some quantitative measurements. Solutions containing from 0.25 gram to 2 grams of potassium sulphate per liter were made up. In these solutions calcium carbonate was suspended, and the solutions were agitated while passing in carbon dioxide for forty minutes. The solutions were kept at 18° C. during the experiment, and a little litmus was added. At first the solution would redden, owing to the action of the carbonic acid on the litmus, but in ten minutes it would become blue, the color intensifying as the reaction progressed. At the end aliquot proportions were filtered and tested as follows:

(1) The total alkalinity was determined by titrating with normal sulphuric acid. (Alkalinity=number of cubic centimeters of the normal acid required.)

(2) The portion was completely evaporated and dried at 110°, then leached and the alkalinity of the leachings determined by titration with normal sulphuric acid.

(3) To another portion alcohol was added to make about a 60 per cent alcohol solution, whereupon gelatinous precipitate settled, which, after standing twelve hours, separated into easily recognized crystals of gypsum and calcium carbonate.

From the figures obtained it was concluded that at a point somewhere between the solutions containing one-half gram and 1 gram per liter of potassium sulphate the reaction was complete as to the replacement of the sulphion by the CO_3 ion, but beyond this point the replacement was less complete and the relative amount of the replacement was a regular function of the initial concentration and, further, that the solution did not necessarily become saturated with respect to acid calcium carbonate, nor the composition of the residue affect the alkalinity.

COLORADO.

O'Brine[a] gives an analysis of samples of alkali from near Fort Collins that was composed largely of sodium chloride and sulphate. To counteract alkali in small quantities deep tillage is recommended. When alkali is present in large quantities underdrains are advised. The roots of plants on underdrained land will go deeper for the necessary moisture, and a small quantity of water applied at the proper time will carry off the alkali from the surface soil. The experiment of Professor Cassidy on the college farm is cited. Drain tiles were laid 30 feet apart and 3½ feet deep, discharging into an open ditch. Before the land was drained the ground was covered with a white incrustation of alkali, but none was to be seen after the installation of the underdrains. Drainage is strongly urged for soils that are irrigated with water containing any considerable quantity of alkali salts.

In 1898 Headden[b] undertook the study of the relation of alkali to the growing of sugar beets. The soil selected varied from a loam containing some gravel and having a somewhat calcareous clay subsoil to a fine alluvium, all of the soil to a depth of 5½ feet being retentive of water. Parts of the plat were covered with incrustations of salts one-half-inch thick after irrigation. The conclusions reached are as follows:

Beet seed will germinate freely in soil containing as much as 0.10 per cent of sodic carbonate, but the young plants are injured by as much as 0.05 per cent, and it is doubtful if any of them can survive when there is as much as 0.10 per cent of this salt in the soil. Sodic sulphate affects the germination to a much less degree, even when it is equal to 0.80 per cent of the air-dried soil, but it is injurious when present in larger quantities. When both salts, sodic carbonate and sodic sulphate, are present in equal quantities the action of the carbonate is only slightly or not at all mitigated. Magnesic sulphate retards but does not prevent germination when present in quantities equal to 1 per cent. Sodic salts hasten germination by from thirty-six to forty-eight hours. The effect of the alkali is of itself not detrimental to the sugar content of the beet. The presence of alkali increases the weight of the leaves very slightly and has no marked influence on the date of maturing.

In a subsequent paper Headden[c] announced the further results along this line of investigation. It was found that the application of straw as well as of manure improved the condition of the ground and perceptibly mitigated the effects of the alkali. The force of capillarity caused water to rise 45 inches as a maximum, the surface of the soil being protected from wind and sun.

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[a] Soils and Alkali. By D. O'Brine, Bul. No. 9, Colorado Expt. Sta., 1889.

[b] A Soil Study: Part I. By W. P. Headden. Bul. No. 46, Colorado Expt. Sta., 1898.

[c] A Soil Study: Part II. By W. P. Headden. Bul. No. 58, Colorado Expt. Sta., 1900.

Headden[a] states that alkali is much less injurious in itself than the conditions which admit of its formation. In the incrustations formed upon the soil are sodic, magnesic, and calcic sulphates, and sodic chloride. This is the order of importance in the incrustations, but not in the soil, the sodic and magnesic sulphates forming about 80 per cent of the total salts brought to the surface. The aggregate quantity of soluble salts per acre, whose movement is affected by the water falling as rain or applied to the surface in irrigating and also by its evaporation, is large. The application of water in irrigating may carry the soluble salts so deep into the soil that a long time may be required for them to come to the surface again. Analyses are cited to show how very different the percentages of the various salts are in the alkali and in that portion of the soil which is soluble in water. The water-soluble portion of the soil contains a relatively small quantity of sodic sulphate, while the alkali contains a large quantity. The sodic sulphate, together with the magnesic sulphate, is concentrated in the alkali. The incrustations are formed by the evaporation of water from the surface of the soil which, owing to the deportment of these salts toward capillary action and the chemical instability of the hydrated salts themselves, effects their separation from the soil solutions. Efflorescent alkalies are quite different from the residue left by evaporating bodies, such residues seeming to be intermediate between those obtained by evaporating ground waters to dryness and those brought to the surface by capillarity and appearing as efflorescenses on the ground.

In a later bulletin Headden[b] deals with the subject of the ground water. He states that for the eastern slope of the Rocky Mountains "the question of alkali resolves itself into one of drainage and beyond this there is no alkali question." The presence of alkali salts and whatever injurious effects they may have produced is due principally, if not wholly, to the lack of drainage, which in many instances has been made more apparent and its effect greatly augmented by overirrigation. He further states that he has seen no occurrence of alkalies in the States of the eastern slope where their accumulation was not due to the lack of drainage, the alkalies accumulating in depressions with no outlet, which serve as collecting places for the water draining from the higher ground, or along water courses where the lowness of the land and character of the vegetation prevent proper drainage.

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[a] A Soil Study: Part III. By W. P. Headden. Bul. No. 65, Colorado Expt. Sta., 1901.

[b] A Soil Study: Part IV. By W. P. Headden. Bul. No. 72, Colorado Expt. Sta., 1902.

IDAHO.

Burd,[a] preliminary to a detailed study of the alkali districts of Idaho, discussed in a general way the effects of alkali, its composition, formation, and methods of accumulation in the soils, as well as various methods for the reclamation of lands already strongly impregnated with alkali salts.

Burd,[b] in a subsequent bulletin, describes the results of studies of the soils and alkali conditions in the Payette Valley, situated in the western part of the State. The region studied comprises the basin of the Payette River for the last part of its course, just before its confluence with the Snake River. About 50,000 acres are under existing canals, but not all of this land is cultivated. The greater part of the agricultural land of the valley lies south of the river. The so-called bench lands lying between the river and surrounding hills form one of the principal features of the topography.

Usually the benches are separated from the river by areas of level bottom land. Prior to the opening of the large high-lying ditches some farming was carried on in the lower bottom lands, but later much of the river bottoms was abandoned because of the accumulation of alkali and seepage waters. The soils of the valley as a rule are alluvial silty loams, light in texture and color. On account of the fineness of texture most of the soils do not drain readily. Tables are given showing the results of analyses of eight samples of well water and more than one hundred samples of soils.

In the valley the wide distribution of dark spots and stains on the soils indicates that black alkali is the predominating variety. In the analyses it was found that black alkali is present in greater quantities than the other constituents. In lands whose fertility has been the most affected the carbonate equivalent is frequently as great as 0.3 to 0.5 per cent, which of course precludes any attempt at cultivation. Virgin and cultivated soils, the latter growing fine crops, are shown by the analyses to contain on the average an equivalent of 0.10 per cent or more of sodium carbonate. In general sodium chloride averages less than sodium carbonate and in good growing upland soils amounts to 0.03 per cent or less.

The soluble sulphates frequently run high—from 0.20 to 0.40 per cent—in the moist lands, but in lands growing good crops are present in small quantities as compared with the other salts.

The virgin soils as a rule contain smaller quantities of soluble salts in the surface foot than in succeeding feet. The quantities in the surface foot are usually below the limit of tolerance for nearly all crops, so that while most of the land produces well at the start its ultimate state depends on whether the local conditions are favorable to an increase or decrease of the salts near the surface. In conclusion, Burd states that the quantity of alkali in the valley is quite large and furnishes a serious obstacle to the successful farming of large areas. Irrigation has resulted in improving certain favorably situated soils by working the salts to greater depths, or into the drainage, or onto neighboring lands. But on low-lying lands, or wherever the natural drainage is poor, accumulation of alkali has been brought about. The accumulations consist largely of sodium carbonate. Unfortunately, the use of gypsum is impracticable, because the quantity of resulting sodium sulphate, in addition to the sulphate and chloride already present, would in most cases still be far above the toxic limit for the crops grown. In even the most favorably situated soils the alkali content is quite high, and unless water is sparingly used or the underdrainage is exceptionally good the tendency of the salts to come to the surface is soon observed. The topography of the bench lands is admirably suited to artificial underdrainage, which would probably solve the alkali problem for lands so situated. It is difficult to see how the low-lying river lands could be successfully underdrained, and for the present at least such lands should be avoided or chosen with great care when intended for agricultural purposes.

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[a] J. S. Burd. Alkali and the Treatment of Alkali Lands. Bul. No. 44, Idaho Expt. Sta., 1904.

[b] J. S. Burd. Alkali Conditions in the Payette Valley. Bul. No. 51, Idaho Expt. Sta., 1905.

MONTANA.

Traphagen,[a] in an article on the alkali soils of Montana, discusses the origin of alkali. Near Billings, in the Yellowstone Valley, it was found that the decomposition of the Fort Benton shales furnishes the alkali, which consists largely of sulphates. Numerous cases are cited to show that the rise of the ground water resulted in the swamping of deep-rooted crops and by evaporation in the accumulation of alkali at or near the surface. Many analyses of soils near Billings showed the alkali salts to consist largely of sodium sulphate. Alfalfa is recommended as the ideal crop for alkali lands. Judicious surface flooding is regarded as beneficial. Irrigation should be practiced with caution, and where the farmer can afford it the alkali lands should be underdrained.

Traphagen,[b] in a later bulletin, discusses the origin of alkali salts as found in soils of arid and semiarid districts. The example of a soil derived from the decomposition of granite is given to show the manner in which the various salts are formed. Whether the soluble salts formed by the decomposition of the granite will accumulate depends entirely upon the subsequent history of the soluble portion of the rock. With an excess of water, as in regions with a humid climate, the soluble salts will be removed nearly as fast as formed, but in a district of scant rainfall, where but a small portion of the soluble salts is removed, they will accumulate to an alarming extent where conditions are favorable to this action. The rise of alkali is discussed, as well as the distinction between white and black alkali. The remedies for the rise of alkali are considered under the three heads of prevention, amelioration, and eradication. Prevention resolves itself into two parts. First, avoid as far as possible, by using small amounts of water, the solution of objectionable matters; second, reduce surface evaporation to a minimum. Under the head of amelioration he recommends the plowing under of straw or similar material as soon as possible after irrigation and the planting of such crops as can withstand considerable alkali. The eradication of the alkali can only be brought about by underdrainage. The importance of this method is discussed, and quotations from publications of the Bureau of Soils are introduced to emphasize the desirability of this method.

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[a] The Alkali Soils of Montana. By F. W. Traphagen. Bul. No. 18, Montana Expt. Sta., 1898.

[b] The Alkali Soils of Montana. By F. W. Traphagen. Bul. No. 54, Montana Expt. Sta., 1904.

A table of analyses of 358 samples of alkali soils from different parts of the State is given, showing the content of chloride, sodium sulphate, and sodium carbonate. Traphagen also reports the results of pot experiments with alfalfa, oats, wheat, barley, and timothy in soils containing varying quantities of alkali salts. Five plates are included, showing graphically the results of the pot experiments. The following summary of general results of the experiments is given:

"The presence of magnesium sulphate—epsom salt—in quantity up to 1 per cent has apparently no ill effect upon the growth of alfalfa. The limiting quantity of sodium sulphate—Glauber's salt—for alfalfa seems to be about seven-tenths of 1 per cent. With a mixture of two-thirds sodium sulphate and one-third magnesium sulphate, which represents very closely the composition of Montana alkali, the limiting quantity appears to be about the same as with sodium sulphate alone."

The danger limit for the Montana type of alkali for oats, wheat, barley, and timothy is given as above 1 per cent.

NEW MEXICO.

Goss[a] discusses the value of Rio Grande water for the purpose of irrigation. He states that owing to the presence of gypsum in the water alkali deposited from the Rio Grande must be of the white variety. Daily samples of water were taken from June 1 to November 1, usually for a period of two weeks. These samples were mixed, and at the end of the period an analysis was made of the average sample. The samples were found to vary greatly in composition, the range of water soluble material after evaporation being in the ratio of 1 to 7. As the alkali deposited from the river water is white, the best method for its removal is by means of drains and the use of water, thus washing it out of the land. If possible the river water should not be used for irrigating immediately following a rise due to heavy rains coming after a protracted dry period, as it then contains more alkali. As compared with other rivers, the Rio Grande ranks high for irrigating purposes.

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[a] The Value of Rio Grande Water for the Purpose of Irrigation. By A. Goss. Bul. No. 12, New Mexico Expt. Sta., 1893.

Goss and Griffen[a] describe the alkali conditions in the Rio Grande and Animas valleys. Analyses of soils from the Rio Grande Valley show the alkali to be of the white variety, consisting largely of sulphates and chlorides of soda, with some calcium sulphate, calcium chloride, magnesium sulphate, magnesium chloride, and potassium sulphate.

In the Rio Grande Valley are many low basins near the foothills that receive the drainage from higher lands. This water soon evaporates, and these places have become notoriously bad alkali spots. In the Animas Valley considerable low-lying land is being swamped by the rise of the water table due to excessive irrigation and leaky ditches. In the Animas Valley 0.23 per cent of sodium carbonate in the surface soil was sufficient to prevent entirely the germination of the seeds of ordinary farm crops. Washing out the alkali is urged as the best and most permanent remedy, but it is pointed out that the expense is considerable and that generally the alkali occurs in low-lying lands that are difficult to drain.

Gypsum was applied to soils containing white alkali in the Rio Grande Valley, but the result was purely negative. In Las Animas Valley are patches of soil with no vegetation except greasewood, or "chico," and saltbush (Atriplex). In these patches the soil though sandy is hard and compact. A black incrustation was found in some places. Analysis of a surface crust showed 0.23 per cent of sodium carbonate. Chemical examination of the "chico" showed it to contain large quantities of potash and soda, and plainly showed it to be the immediate source of the black alkali. The roots of the plants extend deep into the ground and for long distances away, and pump up with the soil moisture the material from which the black alkali is formed. This collects in the leaves and stems, and when they drop and decay an accumulation of black alkali results immediately under the bush. Experiments were tried with this soil by placing it in boxes and treating it with gypsum. It was found that the injurious effects were overcome, and sugar-beet seed germinated freely. Tests were then made on alkali spots, and favorable results followed, as seeds sprouted and made some growth, and the physical condition of the soil was improved. The surface crust was then analyzed, and it was found that the carbonate had been changed to white alkali.

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[a] Alkali in the Rio Grande and Animas Valleys. By A. Goss and H. H. Griffen. Bul. No. 22, New Mexico Expt. Sta., 1897.

From experiments at Aztec and Mesilla Park rye was found to be the best of all the cereals in resisting the effects of alkali. In Las Animas Valley the opinion is expressed that the alkali comes chiefly from the highlands bordering the valley.

Tinsley,[a] in a very comprehensive bulletin on alkali, has summarized the work of the different experiment stations and pointed out the alkali problems in New Mexico. Two principal sources from which the accumulation of alkali may be expected are given. The first of these is the accumulation and evaporation of water in low places. The second and the principal cause is the accumulation of sufficient water in the soil to raise the water table high enough for capillarity to supply the water lost by evaporation at the surface.

For the prevention of the accumulation of alkali there are two fundamental principles to be observed. The first is to keep the water table below the point where capillarity can bring up large amounts of water; the second is to reduce surface evaporation to the very least possible amount. The water table may be kept down by open or covered drains. A depth of 3 feet is recommended, and any less depth is regarded as unsafe. To prevent evaporation, surface cultivation and mulching with manure, straw, and other similar materials are advised, and the effect of a covering of vegetation in decreasing evaporation is pointed out. The relation of manure to alkali is discussed. It is pointed out that there seems no possible chemical reaction by which the manure can change the composition of the alkali and render it less injurious, but its use often results in marked benefit. The beneficial action may be due partly to the fact that it tends to loosen the surface soil and partly to the fact that it may act as a stimulant, especially to young plants, and enable them by their greater vigor to resist the action of alkali. For the removal of alkali from the soil three methods are discussed, namely, removing the surface soil, growing resistant plants, and leaching and underdrainage.

In a subsequent bulletin Tinsley[b] published the results of an experiment in drainage and flooding for the removal of alkali. A 20-acre tract was selected in the Hondo bottoms east of Roswell. The soil is rather heavy, much of it being a heavy clay loam. The greater part of the tract was covered with bunch grass—locally called "salt grass"—and part of it with true salt grass. On much of the land the water table was so near the surface that cultivation was impracticable.

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[a] Alkali. By J. D. Tinsley. Bul. No. 42, New Mexico Expt. Sta., 1902.

[b] Drainage and Flooding for the Removal of Alkali. By J. D. Tinsley. Bul. No. 43, New Mexico Expt. Sta., 1902.

The alkali was nearly all of the white variety, consisting of sodium sulphate, magnesium sulphate, calcium sulphate, and sodium chloride, with small quantities of sodium bicarbonate or carbonate. The drainage system consisted of a main central drain 610 feet long, part being an open ditch, part consisting of 8-inch tile, and the upper 240 feet of 6-inch tile. On the east of the central drain were 12 lateral drains. Some of these were laid 30 feet apart and consisted of 3-inch tile between 2 and 3½ feet deep. Other laterals were 40 feet, 60 feet, and 100 feet apart and consisted of 4 and 5 inch tile. The work of installation was completed May 1, 1900. In July, 1900, flooding was commenced. The drains lowered the water table to the depth of the tiles, and in 1901 much of the alkali had been washed from the first and second foot of the soil. Because borders were not adequate to hold the water on the land and because the surface was covered with a hard and compact sod, the leaching away of the alkali did not progress so rapidly as expected.

As a result of the experiment Tinsley concludes that where the water table is within 6 inches or less of the surface the amount of alkali is low. The maximum effect of capillarity in the Hondo meadows soil is found where the water table is about 2 feet below the surface of the ground. Ten floodings removed about one-seventh of the total alkali from the first 2 feet of soil and carried a large proportion of that formerly in the first foot down into the second. He states that combined open and tile drains will cost from $20 to $30 an acre.

Goss[a] gives the results of ash analyses of some New Mexican plants. All the plants of the Territory seem to average higher in ash than the plants of the rainfall district. This is probably due to the more concentrated solutions of mineral matter present in the soils in which they grow. In regard to the mineral contents of plants growing on alkali soils there does not seem to be much uniformity. For example, salt grass and bunch grass, while containing about an average quantity of ash, are much lower in soda, potash, lime, magnesia, and the other elements usually found in alkali than many of the plants growing on the soils containing much less alkali. On the other hand, the sea-blite and chico bush, both alkali-loving plants, are very high in soda and some of the other elements found in alkali. Goss concludes that the species of the plant has perhaps more to do with its mineral composition than the environment under which it grew.

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[a] Ash Analyses of some New Mexican Plants. By A. Goss. Bul. No. 44, New Mexico Expt. Sta., 1903.

WASHINGTON.

In 1901 Heileman[a] described the alkali conditions in the Kittitas and Yakima valleys. In the Kittitas Valley it was shown that while all the land contained some alkali, that which was uncultivated and unirrigated showed the least. It was also shown that land irrigated with the least quantity of water showed less surface alkali than land lying adjacent to irrigating canals. In all cases where unlimited or excessive quantities of water were obtainable for irrigation there were found tracts which were entirely unfit for cultivation. It was found that the natural drainage of the land was unfavorable for the rapid elimination of seepage water or alkali-charged water into the river. Natural drainage in many places is hindered by a layer of calcareous hardpan, which checks the drainage and favors the retention of the alkali above it. The source of the alkali seems to be the soil in the valley, with accumulation and concentration in the lower basinlike depressions. The alkali consists mainly of carbonates, with sulphates and chlorides present in limited quantities. The use of land plaster or gypsum is recommended to overcome the injurious effects of the black alkali.

An experiment in the reclamation of alkali land is also described. This was on Mr. Tjossem's farm in the Ellensburg district. A mole plow, so constructed that a wooden box could be drawn after it through the soil, was used and the field satisfactorily drained and then flooded. The results of this experiment were excellent, good crops being raised on land that before had supported only the alkali-resistant salt grass.

In the Yakima Valley both carbonates and sulphates were found and often sodium chloride. The greater part of the alkali is sodium sulphate. The soil does not show a high percentage of lime or magnesium carbonates.

WYOMING.

Buffum,[b] in speaking of the effects of alkali, states that the greatest injury to plants is due to the alkali interfering with the life function of absorption, and probably also of assimilation, in the plant economy. If present in small quantities, the growth is merely retarded, while if the soil contains larger quantities of salts, the growth is entirely stopped or the plant destroyed.

A series of tests were made to determine the effect of alkali on the germination and early growth of various plants. A portion of soil was washed until it showed no traces of sulphates or chlorides. Then different percentages of alkali were incorporated with the soil and enough water added so that in each case there was 25 per cent of water in the soil when the seeds were planted. It was found that even a small percentage of alkali retarded germination, and the greater the quantity, up to the amount necessary entirely to prevent development of the germ, the greater the time necessary for the seeds to germinate. The experiments demonstrated that alkali has a physiological effect on the vitality of the seed and plant. The results in tabular form showed that some crops can withstand greater quantities of alkali than others. Rye was found to grow upon soil containing comparatively large quantities of alkali. Wheat comes next in point of resistance, then barley, and lastly oats. Turnips were found quite susceptible to alkali, while alfalfa would germinate in soils containing moderate quantities of alkali. The reason why alkali retards or prevents development was not satisfactorily determined. It was found that the water did not readily enter the seed when the soil contained from 5 to 15 per cent of alkali, and the seed swelled slowly. The outer seed coat on wheat and rye seemed to swell faster than the starch inside, leaving the kernel loose and wrinkled. No apparent change could be detected in the germ, even when examined under a high-power microscope, and it would seem that the physiological effect produced by alkali is not necessarily fatal to the life of the germ.

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[a] Alkali and Alkali Soils. By W. H. Heileman. Bul. No. 49, Washington Expt. Sta., 1901

[b] Alkali. By B. C. Buffum. Bul. No. 29, Wyoming Expt. Sta., 1896.

The reclamation of alkali land was tried upon one of the station farms. A series of open ditches were dug around and upon the Sheridan farm. They were so constructed that the water in times of heavy rainfall or when the land was irrigated would be drained away to a depth of 2 feet below the surface. Reports one year later showed marked improvement, and it was believed the land would be entirely reclaimed.

In a subsequent bulletin Slosson[a] discussed the character of alkali found in Wyoming. Almost all the alkali in the State was found to consist of three salts—sodium sulphate, magnesium sulphate, and sodium chloride—in varying proportions. Sodium carbonate is very rare. The alkali salts are noted as occurring in large beds of single salts, often very pure. Near Laramie are beds of sodium sulphate, near Rock Creek beds of magnesium sulphate, and near Green River beds of sodium carbonate, many acres in extent and several feet in thickness.

The origin of the "alkali lakes" is discussed. The origin of the salts, it is stated, need not be considered if it is remembered that the kinds of salts deposited from a solution depend upon the proportions of the different salts, the temperature of the solution, and the degree of concentration, and need not be the same as the salts dissolved. Slosson states it is not impossible that a consideration of the simpler reactions may throw light on the probable way in which pure salt deposits have been formed. Starting with a solution, such as natural waters, containing the bases calcium, magnesium, and sodium and the acids carbonic, sulphuric, and hydrochloric, the most insoluble compound would be first precipitated. This is calcium carbonate, or a mixture of calcium and magnesium carbonates, forming beds of limestone or dolomite. The calcium sulphate would next be deposited in the form of gypsum, and it is mentioned that beds of gypsum of great thickness exist in many parts of the State, as at Red Buttes. In the Laramie Plains gypsum was found at intervals in boring to a depth of 1,000 feet. If sodium was originally extracted from the rocks in the form of carbonate, the absence of this salt in most of the State could be accounted for by the reaction between sodium carbonate and calcium sulphate to form sodium sulphate and limestone.

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[a] Alkali Studies: II. By E. E. Slosson and B. C. Buffum. Bul. No. 39, Wyoming Expt. Sta., 1898.

If both the calcium and the carbonic acid were completely precipitated, there would be left as possible compounds magnesium chloride and magnesium sulphate and sodium chloride and sodium sulphate. Of these, magnesium chloride is by far the most soluble at ordinary temperature and would therefore be the last salt deposited in and the first washed out from an alkali bed. In the waters of the State the sulphates are in large excess over the chlorides, so magnesium chloride may be regarded as practically absent, and the salts formed would only be magnesium sulphate, sodium sulphate, and sodium chloride. Analyses show that all alkali of the State consists of these three salts in varying proportions. There are beds of the first two, but so far no deposits of sodium chloride have been found.

A study was made of the absorption of water from alkali solutions by seeds. Experiments were carried on with wheat seed, and it was found that the absorption of water was not influenced by the kind of alkali nor the strength of the solution, but purely by osmotic pressure. Solutions of sugar, sodium sulphate, magnesium sulphate, and sodium chloride were so made as to have the same osmotic pressure, and it was found that wheat absorbed just about the same quantity from each of these in the same length of time. Beans absorbed the same quantity of water, whether it was pure or a saturated solution of common salt. The dissolved salt passed into the bean apparently as readily as water and destroyed the power of germination. With the exception of sodium carbonate it was not found that the salts mentioned exerted any poisonous influence on the wheat, as it germinated readily when removed from the alkali solution and put under favorable conditions. The absorption of water is retarded and diminished by the pressure of salts in the water, but not prevented. This is due to the fact that the seed allows the salt to pass into it, though not so readily as the water. The volume of the swelled seed and the amount of salt they contained were determined, and it appeared that in strong solutions enough salt was absorbed to make the solution inside the seed nearly the same strength as the outside. In this way the resistance to absorption of water due to osmotic pressure is diminished. The same means of obtaining water from a strong salt solution is probably used by such plants as the salt sage, which contains a large amount of mineral salts. This has the double advantage of aiding the plant to drain water from the soil and better to keep what water it has, because the salts dissolved in the sap lessen the evaporation.

Knight,[a] in discussing the alkali lakes and deposits of Wyoming, states that in addition to large areas of soils containing alkali, where there are exposures of clays, shales, and sandstone, even though soils do not exist, there are also accumulations of the various salts. These come from the rocks in place, there being sufficient moisture to bring the alkali to the surface. In such cases the source of the salts is traceable to the original sedimentary rocks. All of the formations from the Triassic up to the Tertiary, inclusive, contain more or less of these various compounds. In some localities the quantity of alkali stored in clays and shales is enormous. In the Red Desert there are clay beds of a dull-red color. Only a few inches below the surface the alkali often amounts to 30 or 40 per cent of the mass. In addition, many springs contain unusual quantities of salts, one being mentioned that contains 10 per cent of sodium carbonate.

The point is brought out that, while all deposits of alkali occur in undrained depressions, the depressions surrounded by Paleozoic and Mesozoic rocks contain only very slight quantities of alkali. This may be explained by the fact that the territory draining into the depressions contains little or no alkali, or else the underground drainage may be sufficient to permit the salts to be drained away.

The granite soils were examined and found to be remarkably free from alkali. It was found that the feldspars were not undergoing rapid decay. Weathering of the granites along the mountain ranges in arid regions results in the separation of the quartz and perhaps the oxidation of the mica and hornblende, and consequently but little soil is being formed, and all of the salts appear to be washed into the streams and in no instance to be stored upon the land. Since nearly all of the granites of this State have orthoclase as the dominant feldspar, the alkali produced should be potassium, but all of the deposits are almost free from any of the potassium salts.

The older series of rocks were examined, including the Algonkian, Paleozoic, Cambrian, Ordovician, Carboniferous, and Permian, but no alkali was found associated with any of these. Even in localities where these rocks were comparatively level and where natural conditions favored the accumulation of various salts none was found.

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[a] Alkali Lakes and Deposits. By W. C. Knight and E. E. Slosson. Bul. No. 49, Wyoming Expt. Sta., 1901.

Analyses of soils derived from the more recent geological formations contain many times as much alkali as those derived from the older rocks, and the waters flowing through them contain vastly more salts. Knight states that primarily the alkali has been produced by the decomposition of the various rocks containing these elements. These salts appear to have been formed extensively during the Mesozoic and Cenozoic eras, but in place of being stored in deposits were carried down with the sediments. Later, through mountain-making agencies, these formations were brought to the surface and through weathering have been converted into soil. The salts have remained in the soils so formed, since there has not been sufficient water to leach them out. The decomposition of the rocks is still in progress, and from this source and the stores already accumulated in the soils the deposits of alkali have been formed and are being increased.

There are hundreds of places in Wyoming where sodium salts are being accumulated, but as a rule they do not form beds of much importance. The deposits vary in size from a few acres to 100 acres or more and in thickness from a few inches to 10 or possibly 15 feet. The salts are always found resting upon a muddy bed, which is usually very salt. The mud varies in color from almost black to bluish and contains many crystals of sodium sulphate. When it is removed from the bed it has a strong odor of sulphuretted hydrogen and the odor often resembles that rising from dissolving sodium hyposulphate. This mud always contains quite a high percentage of the salts found in the deposits.

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SOIL AND ALKALI SURVEYS IN IRRIGATED DISTRICTS.

In 1899 the Bureau (then the Division) of Soils undertook the study of soil and alkali conditions in the western irrigated districts. The results of this work have been published in the Field Operations of the Bureau of Soils. Inasmuch as the various reports describe in considerable detail the exact soil and alkali conditions in a great number of districts located in many of the arid States and Territories, and since they fully discuss the individual alkali problems of each area, it is thought this material assembled in one paper will be of great value to those interested in the subject of alkali investigations.

PECOS VALLEY, NEW MEXICO.

This area was surveyed in 1899 by Thomas H. Means and Frank D. Gardner.

The Pecos Valley is situated in the eastern part of the Territory of New Mexico and extends in a north and south direction along each side of the river bearing the same name. Its climatic conditions are characterized by a mild temperature, low relative humidity, abundant sunshine, and low rainfall. The mean rainfall is approximately 15 inches per annum and is not sufficient to produce more than a meager growth of vegetation. Irrigation is necessary, therefore, to carry on agricultural operations successfully. The soils of the valley are for the most part sands or sandy loams, gypsum, and conglomerate or gravel.

Extensive irrigation did not begin in this region until 1889, and for a few years following that date the region was extensively boomed. Large systems of irrigation canals and reservoirs were built at a cost of several millions of dollars. The soils before being placed under irrigation were almost always comparatively free from alkali, rarely containing more than 0.25 per cent of total soluble salts, and usually an amount considerably below this. After irrigation had been carried on for a few years, alkali began to make its appearance in certain places in sufficient quantities to be harmful to plants, and it was largely as a result of these conditions that the soil and alkali survey was made there in 1899. This work brought out the fact that the

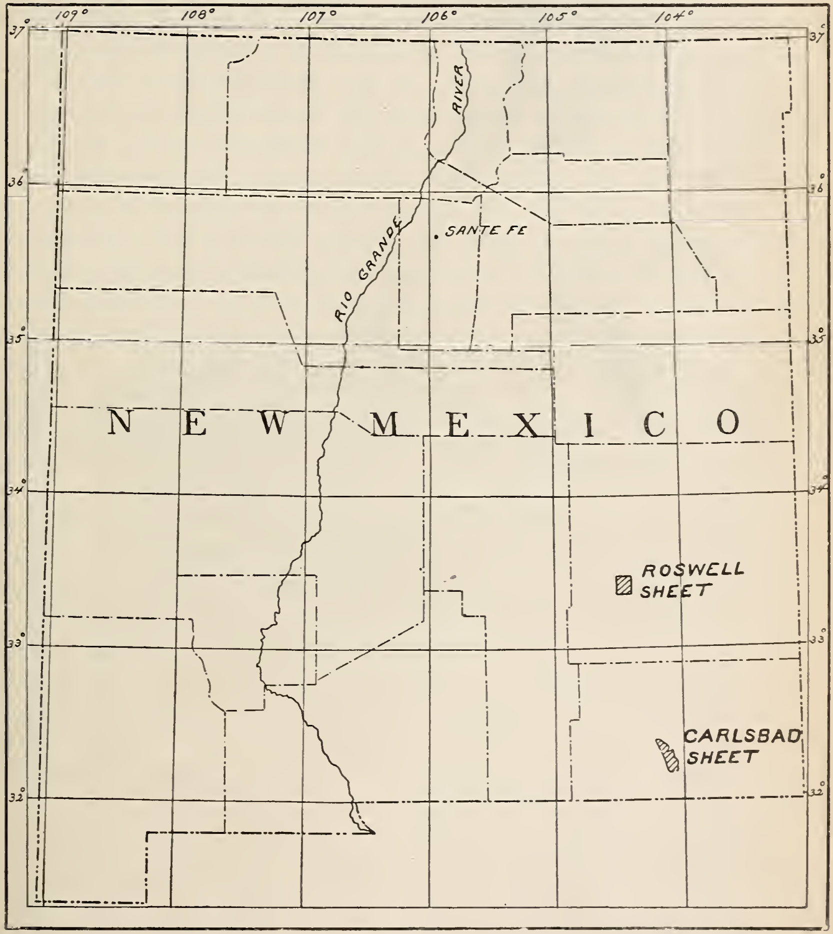

FIG. 1.—Sketch map showing location of areas in which alkali has been studied in New Mexico.

water supply for the upper part of the valley, especially that which was secured from the North and South Spring River and the artesian waters, which evidently rise from the same source, was very good, containing on an average about 75 parts of soluble salts per 100,000 parts of water. Of those salts about two-thirds were comprised of sulphate and carbonate of lime, which, as the water evaporated and the solution became more concentrated, crystallized out before a sufficient concentration was reached to be injurious to most plants. Farther down in the valley, however, where the water was taken directly from the Pecos River, it contained a higher percentage of salts, the percentage increasing as the distance down the valley increased. The water at Hagerman was found to contain 200 parts, at Carlsbad 240, at Florence 282, at Red Bluffs 316, and at Barstow, near Pecos City, 420 parts, while below Barstow the water from the river was found to contain 526 parts of salts per 100,000 of water, or a concentration which in itself was almost sufficient to kill plants.

By the use of irrigation water containing such a large quantity of alkali the soil gradually increased in alkali content until areas where seepage waters had begun to accumulate contained sufficient alkali to prevent the growth of ordinary crops. The alkali, both in the water and the soil, is white, and from 50 to 80 per cent of it is made up of sulphates and carbonates of lime, magnesia, and soda. The presence of calcium sulphate explains why black alkali is not found in this region.

The gypsum land and the conglomerate are both sources of considerable trouble in irrigation. The gypsum soil washes very badly, and small laterals often cut down to a depth of 9 or 10 feet below the surface. The seepage from ditches is very large, not only causing a loss of water, but also accumulating in the soil to such an extent that it causes a rise of the alkali. In the case of the conglomerate soil there is little or no trouble from washing, but the soil contains such a large percentage of gravel that water passes through it very rapidly, and as a result many of the canals lose a great deal by leakage. It is also difficult to irrigate this soil, because the water passes down through it so rapidly that it is impossible to flood more than a very small area with a small stream of water. The rise of the ground water and the accumulation of alkali in various places in the valley is due to the bad condition of the water and the large amount of seepage from the canals and from overirrigated land.

SALT LAKE VALLEY, UTAH.

This soil survey was made in 1899 by Frank D. Gardner and John Stewart. The virgin soils usually contain considerable alkali. Where nature has provided good drainage the alkali moves downward upon the application of irrigation water and does no harm, but where drainage is poor it is necessary to provide artificial drains in order to reclaim alkali land.

The source of the alkali is the water of Great Salt Lake, which, within the memory of the older inhabitants, has covered much of the low-lying lands, or from the waters of its predecessor, Lake Bonneville, in the case of the more elevated lands.

The alkali is composed largely of chloride of soda, with a lesser amount of sulphate of soda and a small percentage of chlorides, sulphates, and carbonates of lime and magnesia. Sodium carbonate or black alkali is frequently present in very small quantities, and in many places occurs in sufficient quantity to be injurious to vegetation. Wherever present in such quantities, however, it is accompanied by white alkali also in sufficient amount to prevent the growth of crops.

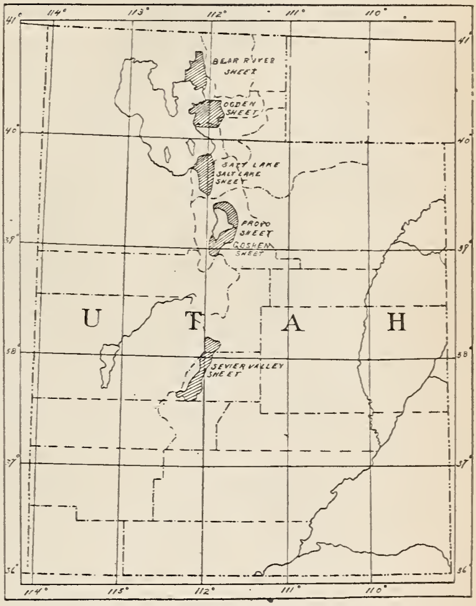

FIG. 2.—Sketch map showing location of areas in which alkali has been studied in Utah.

The water supply is usually of good quality. That for the lands west of the Jordan River is mostly from Utah Lake, and that from the east is derived directly from the mountain streams. The source of Utah Lake water is also chiefly the mountain streams. Seepage water from adjacent irrigated land, together with evaporation from its surface, increases the salt content of the lake water, but not in sufficient degree to make the water harmful for irrigation purposes. The salts of the irrigation water are of the same kinds as those in the soil. The percentage of chlorides is slightly less, while the sulphates are correspondingly increased.

Overirrigation and leakage from canals are the sources of considerable trouble and have resulted in considerable damage to land. Such lands can best be redeemed by thorough underdrainage and flooding. The same method will be required for the reclamation of the low-lying and salty lands.

SANPETE, CACHE, AND UTAH COUNTIES, UTAH.

Means in 1899 made a rapid survey of the alkali soils of these counties with the following results:

Utah County lies directly around the fresh-water lake of the same name. The soils are the sediments of ancient Lake Bonneville, modified by weathering and inflowing streams. Irrigation water of excellent quantity is obtained from mountain streams. Parts of the country have been cultivated nearly forty years. When the valley was first settled land immediately adjacent to Utah Lake was wet and swampy. By irrigating the upland the wet land has greatly increased in area, but is still of value as grazing land. The principal damage is from seepage waters, but where the soil is heavy salts have accumulated at the surface in sufficient quantities seriously to damage the lowlands. Moderate quantities of salts are everywhere present in the soil, and through the agency of irrigation and seepage waters they have been concentrated in small areas.

Sanpete County is located in the central part of the State, and its farming lands lie in the valleys of Sanpete and Sevier rivers. These valleys are quite level and slope gradually toward the mountains. The irrigation water is not so good as in Utah County, and some of it is so bad that its use is attended with risk unless precautions are taken to prevent concentration in the soil.

Cache County lies in the north central part of the State. Irrigating water of excellent quality is taken directly from the tributaries of Bear River.

The soils of Cache and Utah counties are ancient lake sediments. The soils of Sanpete County were formed from materials brought down from adjacent mountains, but they are very similar to those of the other counties. The soils vary from light sand and small gravel to the heaviest and most tenacious clays.

In Utah and Cache counties both white and black alkali are present. Analyses of samples of black alkali crusts from Utah County show as much as 20 per cent of sodium carbonate and nearly 80 per cent of sodium chloride. Crusts of white alkali show large quantities of sodium sulphate as well as sodium chloride. Crusts from the shore of Utah Lake show sodium chloride as the prevailing salt, with 33 per cent of magnesium sulphate. In Cache County black alkali is limited to spots in the west central part of the valley and is always associated with the white alkali. A sample from a tule swamp shows 39 per cent of magnesium sulphate, 36 per cent of sodium sulphate, and 22 per cent of sodium chloride. A crust of black alkali showed on analysis 46 per cent of sodium sulphate, 41 per cent of sodium chloride, and 12 per cent of sodium carbonate.

In Sanpete County the alkali so far as examined was all white. The presence of gypsum in nearly all the soils and in the irrigation waters would lead one to expect this. Analyses of representative samples showed sodium sulphate as the principal salt, with considerable amounts of sodium chloride.

The reconnoissance in the three counties showed that the presence of alkali in the soils was due to defective natural drainage. The obvious remedy is artificial drainage. As tile-drains offer the most effective, and in the end the cheapest method of drainage, their use is recommended. On black alkali soils gypsum is recommended.

Means in 1899 made a reconnoissance in the Cache la Poudre Valley, Colorado, but as this valley was subsequently surveyed and the soils studied in detail by Holmes and Neill in 1904, it will not be considered further at this point.

WEBER COUNTY, UTAH.

Weber county was surveyed in 1900 by Frank D. Gardner and Charles A. Jensen. Irrigation in this district is more than half a century old, having been commenced soon after the Mormons settled at Salt Lake City in 1847. The climate, water, soils, and alkali are essentially the same as those of Salt Lake Valley.

Agriculture is usually of the intensive type. The farms are small, well cultivated, and devoted chiefly to the growing of sugar beets, fruits, and vegetables, especially tomatoes for canning.

The mean annual precipitation is about 14 inches, of which less than 4 inches occur during the growing season. In the adjacent mountains the precipitation is greater, and a considerable part of it occurs as snow, which on the higher peaks lingers through the greater part of the summer. The snow of the mountains is important in relation to irrigation, since it is the source of water exceptionally free from salts, and by its gradual melting prolongs the flow of water in the streams. The canals are usually owned by the proprietors of the lands which they supply with water.

The soils are usually sandy loams, with smaller areas of sands and loams. The low-lying land near the lake shore contains 3 to 10 per cent of salt in the first 6 feet of soil, and is usually bare of vegetation.

The water supply is excellent, and comes chiefly from Weber and Ogden rivers. The annual flow from those two streams is nearly half a million acre-feet. With storage facilities to impound all the water the acreage of irrigated land could be greatly extended. The salt content is low, and 70 per cent of it is in the form of bicarbonates.

Leakage from canals and the application of more water than necessary in the practice of irrigation has caused a rise of the ground-water table to a point which in many places is dangerously near the surface. The remedy for such conditions is greater care in irrigation and the prevention of seepage from the canals, thus economizing water. In many cases it will be necessary to resort to underdrainage in order to reclaim the lands.

The alkali of the district originates largely from the waters of Great Salt Lake, which in no very remote period has covered the greater portion of the irrigated lands of the district. About 64 per cent of the salts occur as chlorides, of which common salt is the usual form, 15 per cent as sulphates, and 11 per cent each of carbonates and bicarbonates. Interesting observations are made upon the variations in the composition of the alkali as found on the surface and at varying depths in the soil.

The use of underdrainage is emphasized as a means of reclamation and of preventing the destruction of lands under which the water table is constantly rising.

SEVIER VALLEY, UTAH.

The Sevier Valley area is located south of the center of Utah, in the counties of Sevier and Sanpete, and was surveyed by Frank D. Gardner and Charles A. Jensen. This portion of the valley extends in a general northeasterly direction from the town of Joseph at the south for a distance of 45 miles to the town of Gunnison. The average altitude of the valley is about 5,000 feet above sea level, while the adjacent mountains on each side rise from 2,000 to 6,000 feet higher.

The climate is arid, the mean annual rainfall being about 8½ inches, and for the year in which the survey was made the total rainfall was less than 2 inches. In general the valley is level, with a fall of about 7 feet per mile in the direction of the river, and about the same fall from the mountains toward the river, excepting near the foothills, where the inclination gradually becomes greater. The soils, usually light in texture, are formed largely from débris brought down from the adjacent mountains and, owing to their derivation, are very diversified in character. As a rule, the virgin soils of the valley are salty, owing to the fact that the salts are formed faster by the rapid disintegration of rocks than they are carried away by the scanty rainfall. In the upper part of the valley, about Joseph, Elsinore, and Monroe, the underlying gravel affords such excellent drainage that when the lands are placed under irrigation the salts are soon carried deep into the soil, where they do no harm and are eventually carried by the seepage waters into the river. Where natural drainage is poor it is difficult to bring these lands into cultivation without the aid of artificial drainage.

The native vegetation of the valley is distinctly arid in its character, and bears an intimate relation to the character of the soil and its salt content. The presence of salt grass and foxtail indicates plenty of moisture near the surface of the ground, and consequently free ground water not far below the surface, while the salt grass is especially indicative of a considerable amount of salts at the surface of the ground. The greasewood indicates dry land of medium texture containing considerable salt, and if the growth is heavy and excludes other plants it is a sure indication of 0.6 per cent or more of salt in the upper 5 feet of soil. If it is less flourishing and gives way partly to shadscale, the salt content will be found less than 0.6 per cent, while the shadscale alone indicates dry land containing less than 0.4 per cent. Rabbit bush does best on sandy soils that are comparatively free from alkali and seldom occurs under any other conditions. Sweet clover and foxtail in fields of alfalfa or grain which have a poor stand indicate wet land and probably from 0.2 to 0.4 per cent salts.

A few small canals were constructed in this valley prior to 1870, but most of them were built during the period from 1870 to 1880. The chief crops are alfalfa, oats, wheat, and barley. The irrigation water supply for the area is entirely inadequate to irrigate all the land unless storage is resorted to. By impounding all the waters from the close of one irrigation season to the beginning of the next enough water might be secured to irrigate all of the arable lands in the district. A reservoir with a capacity of 40,000 acre-feet has been constructed some distance above the district on Otter Creek, and on the Sanpete River between Manatee and Sterling there is a smaller reservoir which has been used for several years in irrigating land about Gunnison and Centerfield. Water being scarce, the farmers irrigate their fields by the furrow method, which consists in running parallel furrows 3 or 4 inches in depth at intervals of from 2 to 2½ feet down the slope of the field and turning the water into these furrows.

The water of all the canals taken from the river above Elsinore contains very little salt even at its lowest stage. Water taken from the river where irrigated lands are adjacent contains more salt, and the quantity increases as the distance downstream increases. Large springs at Richfield, Glenwood, and Redmond furnish water sufficient to irrigate considerable land. The spring waters, as a rule, contain slightly more salt than the water from the upper part of the river, but rarely carry more than 65 parts per 100,000, while artesian well waters have approximately the same composition as that from the springs. Water in surface wells, however, is usually very salty, and the mean salt content of waters from 13 wells was found to be 200 parts of salt per 100,000 of water, some of the wells running up as high as one-half of 1 per cent of salts. In the artesian and spring waters the bicarbonates constitute somewhat more than half, whereas in the seepage waters the chlorides exceed in amount those of all other salts combined.

The alkali consists of chlorides, sulphates, carbonates, and bicarbonates. The bicarbonates are always present in considerable abundance, while the carbonates are frequently present in small quantities only. The chlorides occur in greatest abundance in the lower part of the valley, their source being the beds of rock salt that are found in the mountains near Salina and Redmond. Throughout the district lime and magnesia carbonates are very plentiful, and are responsible for the large percentages of bicarbonates that are frequently present.

SALT RIVER VALLEY, ARIZONA.

Three areas were surveyed in 1900 by Thomas H. Means in the Salt River Valley. These covered areas around Tempe, Phoenix, and Buckeye. As the soil and alkali conditions varied somewhat in each area they may for convenience be discussed separately.

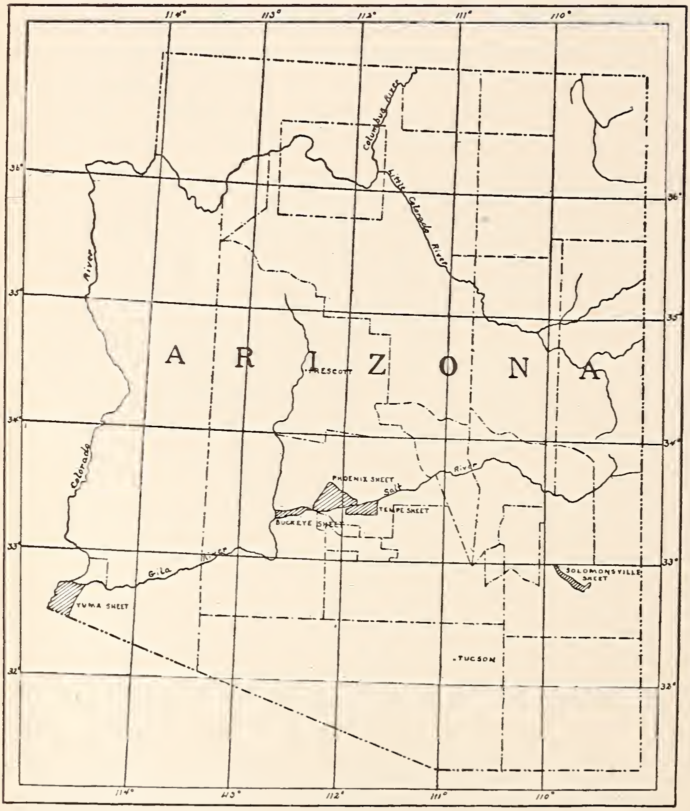

FIG. 3.—Sketch map showing location of areas in which alkali has been studied in Arizona.

The Tempe area comprises that part of Salt River Valley first settled by the modern irrigator. The soils of this district vary from a loam to gravelly loam and sand, all underlain by coarse, loose, incoherent gravel. Two terraces are included. Gravel from the lower levels of the upper terrace outcrops as a bluff that divides the two at a point southeast of Tempe. Nearly all the lower terrace was irrigated in prehistoric times and, at the time of its occupation by modern irrigators, was for the most part alkaline, although the water table was below the capillary reach of the surface. This alkali was no doubt due to a rising of the water table at the time of this prehistoric irrigation, and may have been accumulated at the time of the irrigation or after the abandonment of the lands, when, if the water table had been raised near the surface, evaporation would have been great. Upon cultivation by modern irrigators heavy flooding sweetened these lands to such an extent that the crops grown were unaffected by alkali. Alfalfa, which shaded the surface and prevented excessive evaporation, was the principal crop grown. Soon canals were constructed to irrigate the mesa land above, and this, in conjunction with heavy irrigation on the terrace lands, raised the water table so close to the surface that much of the land south of Tempe was swamped. Surrounding the swamped area was a large district that was subirrigated but not swamped. A part of these subirrigated nonswamped lands became badly impregnated with alkali and a part remained extremely fertile. Often the dividing fence line between two farms was the dividing line between nonproductive alkali lands and those that were free from alkali and highly productive. Close investigation discloses the fact that the productive fields invariably are those in which surface leveling is carefully done and in which the farmer has continued to apply in the form of flood irrigation all the water coming to him in the mutual ditch.

With subsoil water at a depth of 5 or 6 feet it would still be easily within the capillary power of the soil to raise the water to the surface, and if fluctuations occur damage might follow from the water alone. The good farms alongside of the bad, however, amply testify to the ability of the farmer to prevent the accumulation of salts with the water table within reach of the surface.

Since about the middle of the nineties the subsoil water has been slowly lowering over this area. This is due to several causes. A series of seasons of slight rainfall has cut off much irrigation upon the highlands and reduced the water supply for the lowlands. A drainage ditch was cut to the gravel bed near Double Buttes to develop water for irrigation to the west of these buttes. Several large pumping plants have been installed on the "South Side" to furnish water for irrigation. As the water table has been lowered many fields that were allowed to become heavily charged with alkali during the heavy irrigation periods have been reclaimed. If a series of years of abundant water supply should occur, as now seems assured by the construction of the Tonto Basin reservoir, the water table would in all likelihood be again raised in spite of the present pumping plants and single drainage ditch. If abundant irrigation be again assured the water table should be carefully observed, and if it approach so near the surface that damage may be done, additional regional drainage should be installed to carry off the surplus ground water and maintain the level at a uniform height. Under natural conditions the underground water flows with the grade of the country till it strikes the obstruction formed by the more or less continuous line of hills that extends across the valley from northeast to southwest. The Double Buttes territory forms a part of the range that terminates to the southward in Salt River Mountains. Drainage ditches to tap the gravel and relieve it of its surplus of water should be constructed to pass north or south of the range, either to the drainage of Salt or Gila rivers.

Across the river to the eastward of the Phoenix survey the Pima Indians have reclaimed several hundred acres of land that was originally full of alkali, simply by following the method of heavy surface flooding. Their practice is to check the land in small basins. Each basin is filled with water, which is left to seep into the soil. Irrigation even for melon and vegetable crops is done in the same way, so that the alkali is washed out and further surface accumulations prevented practically without cultivation. This method is wasteful of water, but reclaims the land.

The alkali of the area about Phoenix is mainly on the lowlands along the river, a part of which was irrigated by the race that peopled this country in prehistoric times. The accumulations on these formerly irrigated lands have taken place much in the same way as the accumulations south of Tempe. The solution of the problem is practically the same as in the Tempe area, except that there is very little land that actually needs drainage. Southwest of Phoenix, however, in the St. Johns country, is quite a large alkali area that is due almost wholly to seepage and subirrigation from modern irrigation. If by heavy flooding and the prevention of evaporation the water table is so raised as to swamp the area, it may be necessary to put in a few deep drains. Careful farm practice should reclaim these lands if there should be an abundance of water for irrigation, since they are near the river, which is below the general level and affords a ready escape for the seepage waters.

Examinations of the waters of Salt River show the presence of soluble salts at all times, and at the low stages of the river the percentage is quite high. Sodium chloride (common salt) is the principal salt found in the waters of the river. There is also an excess of calcium sulphate. The salts found in the soil are quite different from the salts found in the water of the river. A marked characteristic of the salts of the soil is the presence of the high percentage of calcium chloride.

Prior to the application of water there were many limestone nodules throughout the subsoil, in some instances forming a continuous sheet or hardpan. When the irrigation water was added to the soil, reactions took place between the sodium chloride and calcium carbonate to form calcium chloride and sodium carbonate, the sodium carbonate being largely neutralized by the gypsum of the water. As very little salts have been leached from the soils into the drainage of the country, all the salts found in the river water and resulting from its action upon the calcium carbonate of the soil are yet found in these soils.

In the lower parts of the valley these same reactions have taken place, but much of the calcium chloride being very soluble, it has been leached into the country drainage and carried away. The alkali of the St. Johns country, having come principally from seepage from modern irrigation, is abnormally high in this salt.

The alkali of the Buckeye area is found in a long, narrow strip of soil occupying a depression that was probably at one time the channel of the Agua Fria River. Its accumulation is due to a water table that comes within capillary reach of the surface. Occupying as it does a long, narrow strip along the bank of the Gila River, the country has good drainage. Heavy floodings and treatment similar to that employed in the reclamation of land near Tempe should reclaim the greater part of this strip. If the natural drainage will not carry off the water thus added to the subsoil, deep drains extending through the alkali belt may be necessary, but no detailed drainage should be necessary, as the soils are leachy and the general drainage good.

FRESNO AREA, CALIFORNIA.

The Fresno area was surveyed in 1900 by Thomas H. Means and J. Garnett Holmes. The area comprises a broad, gently sloping plain, the soils of which are mainly sandy, very leachy and pervious, and of such a character that regional drainage is naturally poorly developed. All irrigation has been comparatively recent. Until about thirty years ago the whole country was thought valuable only for its native vegetation, which was utilized for pasturage. When irrigation began the water table for the whole area mapped was low, in many cases approximately 100 feet below the surface. Early irrigation was very copious, some lands receiving as much as 27 acre-feet per year. These enormous quantities of water soon raised the water table, till at the time of the examination in 1900 some of the lower part of the area was swamped, and much contained excessive amounts of alkali. Practically all of the irrigation takes place in the spring and early summer months, at which time large quantities of water are brought to the region by the several large canals. This heavy seasonal irrigation results in a rapid rise of the water table, which for all the time is high. After the cessation of irrigation the water subsides gradually, to be again quickly raised the following season. Practically all the crops grown are fruits, grapes, and alfalfa, and all of these are injured by the fluctuations of the water table as well as by the accumulation of alkali.

The alkali and possible drainage problems are complicated by the presence of sodium carbonate as a part of the salts and by the calcium and magnesium carbonate hardpan, which underlies the greater part of the area and is a constant source of this salt.

The damaged part of this area presents the conditions of sandy, leachy soils, through which water moves rapidly, but for which surface drainage is lacking; a high and fluctuating water table with consequent accumulations of alkali at the surface; and the complication of both alkali and drainage problems by the presence of hardpan. Prior to the rise of the water table the hardpan gave very little trouble. While its presence may tax the ingenuity of the farmers to create favorable moisture conditions and prevent evaporation from the surface, it is not in most cases sufficiently near the surface or at the present time so indurated as materially to interfere with proper root development or the percolation of water. While the hardpan may complicate matters, it is a problem to be worked out by the individual and does not materially change the main problems. The real problems of the area are to control or lower the water table beyond the root zone, to reclaim lands already alkaline, and to prevent the rise and further spread of the alkali.

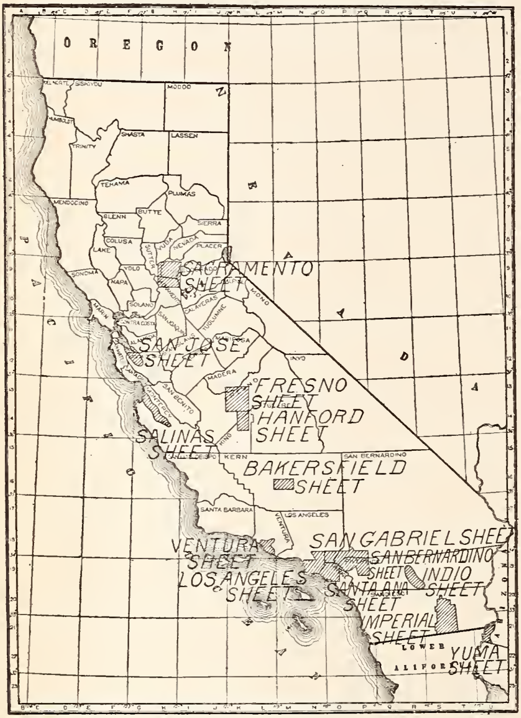

FIG. 4.—Sketch map showing location of areas in which alkali has been studied in California.

The control or lowering of the water table is a definite engineering problem and should be capable of complete solution. The district is one of sandy soils and poor regional drainage; hence to lower the water table drainage should be considered regionally. Drainage may be accomplished either by the construction of gravity drains or by installing pumping plants to supply water for irrigation, and so cutting off the canal supply. Either plan, if comprehensively and intelligently carried out, would accomplish the desired end.

The following table gives a number of analyses of salts of the Fresno district:

Chemical analyses of alkali soils containing no sodium carbonate.

Constituent.	4872. Sec. 19, T. 14 S., R. 22 E., crust.	4841. Sec. 25, T. 14 S., R. 18 E., 0 to 12 inches.	4871. Sec. 7, T. 14 S., R. 23 E., 0 to 24 inches.	4681. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4835. Sec. 22, T. 14 S., R. 19 E., 0 to 12 inches.	4676. Sec. 20, T. 14 S., R. 20 E.	4682.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	18.71	12.59	17.25	1.60	9.51	15.96	2.76
Magnesium (Mg)	8.21	5.26	5.59	.74	3.30	9.33	.56
Sodium (Na)	5.34	15.56	7.93	31.11	21.28	....	33.33
Potassium (K)	.92	1.15	3.50	2.63	1.86	9.33	1.55
Sulphuric acid (SO_4)	1.00	1.60	2.33	25.84	4.54	8.66	7.56
Chlorine (Cl)	64.60	60.40	55.71	33.39	54.55	56.66	53.00
Carbonic acid (CO_3)	....	....	....	....	....	Tr.	....
Bicarbonic acid (HCO_3)	1.31	3.44	7.69	4.69	4.96	....	1.24
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	1.38	2.28	3.27	5.43	6.40	12.00	9.40
Calcium chloride ($CaCl_2$)	50.64	34.61	44.75	....	21.08	34.66	....
Magnesium sulphate ($MgSO_4$)	....	....	....	3.66	....	....	1.14
Magnesium chloride ($MgCl_2$)	32.75	20.49	21.91	....	12.81	35.99	1.34
Potassium sulphate (K_2SO_4)	....	....	....	....	....	....	....
Potassium chloride (KCl)	1.74	2.05	6.53	4.97	3.51	17.34	2.96
Sodium sulphate (Na_2SO_4)	....	....	....	28.25	....	....	....
Sodium chloride (NaCl)	12.32	35.77	13.05	51.23	49.39	....	83.64
Sodium carbonate (Na_2CO_3)	....	....	....	....	....	....	....
Sodium bicarbonate ($NaHCO_3$)	1.77	4.79	10.49	6.46	6.81	....	1.70
Per cent soluble salts	4.61	.87	.86	3.50	.97	.30	8.23

Chemical analyses of alkali soils containing sodium carbonate.

Constituent.	4689. Sec. 2, T. 15 S., R. 19 E., 0 to 12 inches.	4670. Sec. 9, T. 15 S., R. 20 E.	4831. Sec. 3, T. 15 S., R. 19 E., 0 to 12 inches.	4690. Sec. 7, T. 15 S., R. 19 E., 0 to 1 inch.	4668. Sec. 22. T. 14 S., R. 20 E.	4684. Sec. 26, T. 14 S., R. 20 E., 0 to ½ inch.	4839. Sec. 21, T. 14 S., R. 19 E., 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	Tr.	1.81	2.31	Tr.	3.65	....	1.15
Magnesium (Mg)	Tr.	4.64	Tr.	Tr.	1.99	Tr.	Tr.
Sodium (Na)	33.78	19.34	32.41	35.27	23.80	35.26	36.16
Potassium (K)	1.86	19.43	1.85	1.01	10.86	.68	.83
Sulphuric acid (SO_4)	11.97	12.09	5.55	24.03	10.20	12.31	18.91
Chlorine (Cl)	29.92	41.28	36.49	27.11	39.64	22.40	24.50
Carbonic acid (CO_3)	3.19	4.40	5.00	4.99	9.87	10.58	14.90
Bicarbonic acid (HCO_3)	19.28	....	16.29	7.59	....	18.67	3.55
Phosphoric acid (PO_4)	Tr.	....	....	Tr.	....	.10	....
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	....	6.13	8.13	....	12.36	....	3.91
Calcium chloride ($CaCl_2$)	....	....	....	....	....	....	....
Magnesium sulphate ($MgSO_4$)	....	8.12	....	....	1.82	....	....
Magnesium chloride ($MgCl_2$)	....	....	....	....	6.46	....	....
Potassium sulphate (K_2SO_4)	....	2.33	....	....	....	....	....
Potassium chloride (KCl)	3.46	35.05	3.51	1.93	20.65	1.30	1.56
Sodium sulphate (Na_2SO_4)	17.69	....	....	35.57	....	18.23	23.91
Sodium chloride (NaCl)	46.68	40.59	57.31	43.23	41.30	35.93	39.42
Sodium carbonate (Na_2CO_3)	5.72	7.77	8.68	8.82	17.42	18.72	26.34
Sodium bicarbonate ($NaHCO_3$)	26.45	....	22.37	10.45	....	25.72	4.86
Phosphoric acid (PO_4)	....	....	....	....	....	.10	....
Per cent soluble salts	1.50	2.32	1.08	8.30	2.41	24.00	9.19

Chemical analyses of alkali soils containing sodium carbonate—Continued.

Constituent.	4688. Sec. 36, T. 14 S., R. 19 E., 0 to ½ inch.	4829. Sec. 31, T. 14 S., R. 20 E., 0 to 12 inches.	4680. Sec. 30, T. 14 S., R. 20 E., 0 to ½ inch.	4677. Sec. 28, T. 14 S., R. 20 E., crust.	4877. Sec. 8, T. 17 S., R. 21 E., 0 to 12 inches.	4886. Sec. 17, T. 17 S., R. 21 E., crust.	4686. Sec. 19, T. 14 S., R. 20 E. 0 to ½ inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	Tr.	3.52	Tr.	2.55	0.48	0.20	Tr.
Magnesium (Mg)	....	Tr.	Tr.	.50	.16	....	Tr.
Sodium (Na)	36.46	28.74	36.23	31.03	33.77	34.90	36.03
Potassium (K)	.98	.59	.73	5.96	1.81	1.15	.41
Sulphuric acid (SO_4)	8.22	3.81	8.93	17.84	5.44	17.09	5.17
Chlorine (Cl)	24.97	4.99	15.58	21.86	8.06	2.50	5.81
Carbonic acid (CO_3)	15.26	16.71	20.26	20.31	22.63	23.56	26.30
Bicarbonic acid (HCO_3)	13.61	41.64	17.81	....	27.65	20.60	26.01
Phosphoric acid (PO_4)	.50	....	.46	....	....	....	.27
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	....	5.28	....	8.32	1.60	.67	....
Calcium chloride ($CaCl_2$)	....	[a] 8.21	....	....	....	....	....
Magnesium sulphate ($MgSO_4$)	....	....	....	2.46	.75	....	....
Magnesium chloride ($MgCl_2$)	....	....	....	....	....	....	....
Potassium sulphate (K_2SO_4)	....	....	....	13.28	....	....	....
Potassium chloride (KCl)	1.86	1.17	1.37	....	3.47	2.19	.79
Sodium sulphate (Na_2SO_4)	12.16	....	13.20	3.96	5.50	24.69	7.65
Sodium chloride (NaCl)	39.73	7.04	24.64	36.04	10.72	2.39	8.95
Sodium carbonate (Na_2CO_3)	27.02	29.62	35.81	35.90	39.96	41.67	46.51
Sodium bicarbonate ($NaHCO_3$)	18.73	48.68	24.52	....	38.00	28.39	35.83
Phosphoric acid (PO_4)	.50	....	.46	....	....	....	.27
Per cent soluble salts.	6.76	.68	9.92	3.99	3.75	28.22	26.07

Constituent.	4862. Sec. 34, T. 13 S., R. 23 E., crust.	4679. Sec. 22, T. 14 S., R. 20 E., 0 to ½ inch.	4669. Sec. 34, T. 14 S., R. 20 E., crust.	4888. Sec. 9, T. 17 S., R. 22 E., 0 to 24 inches.	4678. Sec. 18, T. 14 S., R. 20 E., crust.	4889. Sec. 11, T. 17 S., R. 21 E., crust.	Standard solution.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	4.58	Tr.	1.75	3.01	0.48	0.04	0.10
Magnesium (Mg)	Tr.	Tr.	.42	....	.21	....	....
Sodium (Na)	31.46	37.26	30.66	34.19	35.03	41.85	34.24
Potassium (K)	.76	1.12	9.87	.63	7.85	1.26	5.33
Sulphuric acid (SO_4)	5.34	2.31	9.80	7.24	7.13	2.35	18.92
Chlorine (Cl)	3.05	11.99	15.75	2.41	5.82	1.15	29.75
Carbonic acid (CO_3)	30.84	28.71	31.71	33.85	43.48	52.79	11.59
Bicarbonic acid (HCO_3)	23.97	18.44	....	18.66	....	.56	....
Phosphoric acid (PO_4)	....	.17	....	....	....	....	....
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	7.48	....	5.88	10.28	1.62	.10	.32
Calcium chloride ($CaCl_2$)	[b] 6.11	....	....	....	....	....	....
Magnesium sulphate ($MgSO_4$)	....	....	2.03	....	1.00	....	....
Magnesium chloride ($MgCl_2$)	....	....	....	....	....	....	....
Potassium sulphate (K_2SO_4)	....	....	7.35	....	9.43	....	....
Potassium chloride (KCl)	1.37	2.13	12.67	1.15	6.89	2.41	9.77
Sodium sulphate (Na_2SO_4)	....	3.42	....	....	....	3.36	27.74
Sodium chloride (NaCl)	3.97	18.12	16.03	3.04	4.20	....	41.63
Sodium carbonate (Na_2CO_3)	48.09	50.76	56.06	59.85	76.88	93.35	20.53
Sodium bicarbonate ($NaHCO_3$)	39.98	25.40	....	25.68	....	.77	....
Phosphoric acid (PO_4)	....	.17	....	....	....	....	....
Per cent soluble salts.	1.31	16.42	2.86	1.91	5.81	54.24	....

[a] $Ca(HCO_3)_2$.

[b] $CaCO_3$.

The alkali soils normally contain sodium carbonate, but in special cases, which cover but a small part of the total area of alkali lands, sodium carbonate is wanting. The analyses given in the first table show the composition of the soluble portions of a number of such soils. All of the samples, except 4681, instead of showing sodium carbonate show large quantities of chlorine, which must be largely combined with lime and magnesium as chlorides. The accumulation of calcium and magnesium chlorides is the result of the action of sodium chloride upon calcium carbonate. Both being in solution at the same time, calcium chloride must exist in the solution. Calcium chloride is a salt which moves very rapidly in a soil. Some experiments[a] made with various chlorides showed that calcium chloride would be washed from a soil in one-half the time required to leach out the same quantity of sodium chloride. As the water moves through the soil the tendency is for the calcium chloride to move more rapidly than the other salts, and hence it accumulates in the place when these waters have evaporated. The extent of these white alkali spots is not large.

Sample 4681 was collected from a spot which had been treated with gypsum, which accounts for the large quantity of sulphates found in the salts.

The second table contains analyses of samples of alkali crusts which contain sodium carbonate. The analyses are arranged according to the content of sodium carbonate, which varies from nearly 6 per cent to over 93 per cent of the soluble portion of the soil. The principal constituents of the soil are seen to be chlorides and carbonates with bicarbonates. Lime and magnesium are low, so that the salts are largely salts of sodium and potassium. Potassium forms an average of 5 per cent of the soluble matter within the soil. Sulphuric acid is always present, but the quantity is rather variable and on the average constitutes 6 per cent of the total alkali salts. The relation between the carbonates and bicarbonates varies greatly as found in the field. The drying out of the samples in transit to the laboratory so changes the relative proportion of these two salts that a laboratory examination gives no idea of the relations which exist in the undisturbed soil. Field examinations were made of many samples for the relation between carbonates and bicarbonates, and even here the relative proportion is found to vary greatly. Carbonates of sodium and potassium have been generally considered the most harmful salts found in the alkali of the soils. Researches in the laboratory of this Bureau show that the bicarbonates are themselves not as harmful as the carbonates, so that a simple statement of the carbonates and bicarbonates from the laboratory determinations does not suffice for a discussion of the field conditions.

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[a] Yearbook, U. S. Dept. Agr., 1898, p. 498.

These alkali crusts containing sodium carbonate occupy almost the entire area of the alkali lands. White-alkali lands are found in very small spots only. The areas of the various grades of alkali soils, as determined from the map, are as follows:

Areas of the different alkali soils.

Grades of alkali soils.	Acres.	Per cent.
Less than 0.20 per cent alkali	336,300	83.8
From 0.20 to 0.40 per cent alkali	26,300	6.6
From 0.40 to 0.60 per cent alkali	10,150	2.5
Over 0.60 per cent alkali	28,500	7.0
Total area	401,250	

YAKIMA AREA, WASHINGTON.

In 1901 Jensen and Olshausen made a soil survey of the Moxee and Atanum valleys and the Sunnyside district in Yakima County, Wash. Irrigation was carried on in this region in a limited way as early as 1860, but the advent of the Northern Pacific Railroad in 1883 really marks the beginning of the agricultural importance of the country. The soils are derived mainly from the sediments of former John Day Lake. These lake beds are composed of alternating strata of volcanic dust, gravel, sand, and finer soils and are also interstratified with widely spread sheets of basalt, as well as a number of more local sheets. Since these beds were deposited the underlying lava beds have been raised and broken in places, giving rise to the present series of ridges and intervening valleys. The soil forming the surface of these valleys varies in thickness from a few feet to upward of 50 or 60 feet.

The prevailing type of soil is the Yakima sandy loam, a light-textured, fine gray sandy loam. Volcanic ash is often found in the soil. With few exceptions this soil is well drained and free from excessive quantities of alkali. Some alkali occurs in the subsoil, but unless the surface of standing water approaches sufficiently near the surface of the ground to permit it to reach the top by capillary movement the amount of alkali is not sufficient to prevent the growing of crops. This, however, does take place, and the soil is then rendered unproductive by such accumulations. Another soil type is the Sunnyside sand, a medium to fine sand, much of which is a wind deposit. This soil is usually well drained and free from alkali. Another soil type is "Meadow," found near the streams in the low bottoms. Some sodium carbonate hardpan was found in a few places along Wide Hollow Creek. A lime hardpan lying about 3 feet below the surface is found in the Sunnyside district.

In the Moxee Valley practically the only places containing injurious amounts of alkali in the first 6 feet of soil are in the eastern and southwestern parts of the valley. The alkali found in the southwestern part of this valley is different from that of the eastern part, as it contains more chloride and less normal carbonate. The alkali seems to come from the foothills, where coatings of salt occur on the slopes.

Along Wide Hollow and Atanum creeks alkali conditions are quite serious. Many tracts that were formerly the best of the area have been abandoned to salt grass and greasewood. The mean salt content in the first 6 feet is not great, being in no place more than four-tenths of 1 per cent. Very often, however, the salt in the first foot is from one-half to three-fourths black alkali, while accumulations on the surface are very common. The amount of chloride is surprisingly small. In the section where the water table is nearest the surface (from 3 to 6 feet) the most alkali occurs. The seepage water from irrigation in the upper part of the valley and from the level lands to the north follows the subsoil strata down to the low places, and there, by capillarity, is brought to the surface to evaporate.

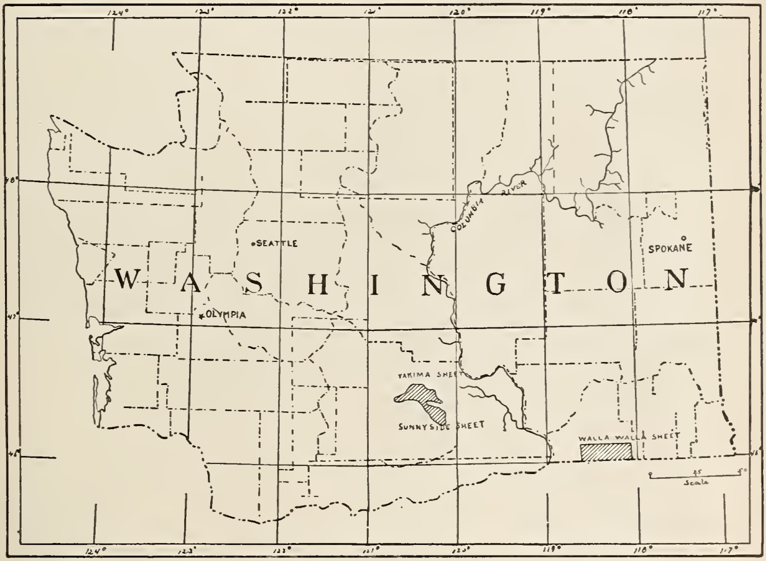

FIG. 5.—Sketch map showing location of areas in which alkali has been studied in Washington.

In the upper part of the Atanum Valley a few trees were found dead or dying on a small spot. Examination of the soil showed in the first foot only 0.15 per cent of salt, while the mean of the first 3 feet was less than 0.10 per cent. As this was mainly carbonate, however, the injurious effects of such slight quantities is accounted for.

In the Sunnyside district the alkali area was not more than 2 square miles in extent. The percentage of salt in this district was from 0.40

to 3 per cent in the first 6 feet, but in about one-half of the affected places it ranged from 1 to 3 per cent. All of this area contained black alkali in the surface foot in quantities varying from 0.05 to 0.30 per cent, but much the greater portion of it carried only 0.05 to 0.10 per cent. The greasewood, which is popularly supposed to indicate alkali soils, was found distributed quite independently either of the total salt content or of the black alkali, though it was always found where a large quantity of salt occurred. The highest percentage of salt occurred in the heaviest phases of the sandy loam. Usually the maximum salt content was in the fourth or fifth foot.

There were alkaline carbonates in all the tests made, and sulphates were always present. The chlorides varied somewhat in relative quantity, but were never high, and the amount of bicarbonate was also moderate. Neither the percentage of the total salt nor of black alkali was high where the soil was light and underlain with sand. In the Parker bottoms a little alkali was found, which was supposed to be black alkali. The soil was colored dark brown and black in places, resembling black alkali, but the salt was bicarbonate and sulphate. It is known that bicarbonates and sulphates have the power of charring organic matter to a slight extent, but the black color may also have been due to the presence earlier in the season of alkaline carbonate which had been converted into the bicarbonate later by aeration. While the soils in the Sunnyside district do not contain any large amount of alkali, great care must be exercised in the use of irrigation water or trouble will ensue.

The following tables contain the results of chemical analyses of alkali in soils:

Chemical analyses of salts in alkali soils.

Constituent.	5815. Meadow near NW. cor. sec. 1, T. 12 N., R. 18 E., soil 0 to 12 inches.	5811. Meadow near NW. cor. sec. 1, T. 12 N., R. 18 E., soil 0 to 12 inches.	5816. Under No. 5815, sandy loam, 12 to 24 inches.	5812. Under No. 5811, sandy loam, 12 to 24 inches.	5813. Under No. 5812, sandy loam, 24 to 36 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.88	3.42	6.28	4.49	4.93
Magnesium (Mg)	.88	3.42	2.09	2.62	2.05
Sodium (Na)	30.69	28.52	19.46	16.11	14.00
Potassium (K)	5.07	4.94	4.79	8.61	9.05
Sulphuric acid (SO_4)	12.80	6.46	.59	1.49	4.52
Chlorine (Cl)	4.63	11.03	4.19	2.62	3.70
Carbonic acid (CO_3)	26.50	42.21	17.37	11.99	8.64
Bicarbonic acid (HCO_3)	18.55	....	45.23	52.07	53.11
Phosphoric acid (PO_4)	....	....	....	Tr.	....
Conventional combinations:					
Calcium sulphate ($CaSO_4$)	2.86	9.12	.89	1.87	6.17
Magnesium sulphate ($MgSO_4$)	4.19	....	....	....	....
Potassium chloride (KCl)	9.71	....	8.98	5.61	7.82
Sodium chloride (NaCl)	....	....	....	....	....
Sodium bicarbonate ($NaHCO_3$)	25.40	....	22.46	36.72	45.28
Sodium carbonate (Na_2CO_3)	46.80	66.94	30.85	13.86	6.58
Sodium sulphate (Na_2SO_4)	11.04	....	....	....	....
Calcium chloride ($CaCl_2$)	....	1.90	....	....	....
Magnesium chloride ($MgCl_2$)	....	13.30	....	....	....
Potassium carbonate (K_2CO_3)	....	8.74	....	9.73	8.64
Calcium bicarbonate ($Ca(HCO_3)_2$)	....	....	24.25	16.48	13.17
Magnesium bicarbonate ($Mg(HCO_3)_2$)	....	....	12.57	15.73	12.34
Per cent soluble	.92	.52	.67	.53	.48

Constituent.	5802. W. cen. sec. 24, T. 9 N., R. 22 E., sandy loam, 0 to 12 inches.	5803. Under No. 5802, sandy loam, 24 to 36 inches.	5804. Under No. 5802, loam, 48 to 60 inches.	5787. SE. cor. sec. 23, T 9 N., R. 22 E., loam, 0 to 12 inches.	5788. Under No. 5787, loam 24 to 36 inches.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.12	1.38	0.91	Tr.	1.86
Magnesium (Mg)	2.66	1.58	.91	0.38	1.70
Sodium (Na)	20.74	26.55	29.10	25.25	26.82
Potassium (K)	7.45	5.94	3.67	10.48	4.80
Sulphuric acid (SO_4)	13.83	23.37	22.68	32.04	27.92
Chlorine (Cl)	7.98	1.98	3.21	18.06	21.72
Carbonic acid (CO_3)	7.98	13.86	12.41	.98	5.42
Bicarbonic acid (HCO_3)	37.24	22.77	24.05	12.81	9.76
Phosphoric acid (PO_4)	....	2.57	3.06	Tr.	....
Conventional combinations:					
Calcium sulphate ($CaSO_4$)	6.91	4.75	3.06	Tr.	6.35
Magnesium sulphate ($MgSO_4$)	12.23	7.72	3.67	1.74	8.37
Potassium chloride (KCl)	14.36	4.15	6.89	20.00	9.14
Sodium chloride (NaCl)	1.59	....	....	13.98	28.50
Sodium bicarbonate ($NaHCO_3$)	51.08	31.50	33.08	17.67	13.33
Sodium carbonate (Na_2CO_3)	13.83	24.57	21.90	1.74	9.61
Sodium sulphate (Na_2SO_4)	....	14.65	26.19	44.87	24.70
Potassium sulphate (K_2SO_4)	....	8.31	....	....	....
Sodium phosphate (Na_3PO_4)	....	4.35	5.21	....	....
Per cent soluble	.38	1.01	1.30	1.03	1.29

Examination of the underground and seepage waters of the Atanum Valley showed them to contain bicarbonate as the principal salt, with only traces of chloride. In the Sunnyside district it was found that the well water was characterized by a rather light percentage of salt, the greater part of which was composed of sulphate and bicarbonate, with smaller quantities of chloride.

In considering the drainage and reclamation of alkali lands Jensen states that the best way to reclaim lands that were originally good and to prevent good land from becoming filled with alkali is to keep the subsoil and seepage waters that carry dissolved salts sufficiently far below the surface to prevent any accumulation of salts through evaporation. If the soil is originally charged with alkali, there is but one sure and permanent cure, and that is to dissolve out the excess of soluble salt by moderate but frequent applications of good water, at the same time draining the water out of the subsoil.

The cause of the damaged lands in Wide Hollow and the Atanum Valley is pointed out. The salts accumulated in these places are alkaline carbonates, or black alkali, and an examination of the seepage water shows that it carries in all cases more than a normal quantity of bicarbonate but no normal carbonate. Examination also showed that the seepage or subsoil water was sufficiently high to be brought to the surface by capillarity of the soil grains, there to be evaporated. There can be but one consequence—the comparatively harmless bicarbonate will lose through evaporation some of its carbon dioxide and be converted into the normal carbonate. As the soil is light in texture in this area, the capillary action goes on quite rapidly. It will be useless, therefore, to try to effect a permanent cure by attempting to change the character of the salt by application of some other salt, as gypsum, for while this will change some of the black alkali to white alkali it only adds more salt to the surface foot, already containing an excess, without in the least decreasing the tendency to form black alkali, which will continue to accumulate as long as the subsoil waters containing bicarbonate are near enough to the surface to be evaporated.

Jensen also calls attention to the dangerous practice in Wide Hollow of allowing the seepage water from above to subirrigate the land. This is a good method to increase the salt content of the soil, and the nearer the water approaches the surface and the longer the practice continues the more salt there will be accumulated. Wide Hollow waste slough forms an excellent natural drainage channel from 5 to 10 feet below the surface of the soil. The soil is light in texture, readily permitting water to percolate through it, and frequent applications of water and a few drains about 4½ feet deep would accomplish much toward reclaiming the land. Another good natural drainage channel is the northern branch of Atanum Creek. Examples of the good effect of drainage in a small way are cited.

A few attempts at reclaiming alkali land have been made in the lower part of Atanum Valley by building a dike around a piece of land and running sufficient water into the inclosed area to cover the field.

After allowing it to stand for a time, the dike is cut and the water drained off. As would be expected, such attempts have usually resulted in the accumulation of more alkali, rather than in reclaiming any portion of the land.

In the Sunnyside district reclamation is perhaps a more difficult problem. The soil is a heavy one in which alkali is found, the maximum amount occurring within 4 or 5 feet of the surface. The absence of any natural drainage channels makes it necessary to dig long ditches to the river.

BOISE AREA, IDAHO.

A study of the soil and alkali conditions of the Boise area was made in 1901 by Jensen and Olshausen. This area contains about 400 square miles and is situated in the southwestern part of the State. Before the building of the Oregon Short Line Railroad, which was completed in the early eighties, the development of agricultural interests in the Boise Valley was very slow.

The principal type of soil is the Boise sandy loam, a grayish sandy loam with a loam or clay loam subsoil, which in turn is underlain with sandy loam, or sometimes a sand cemented together and forming a hardpan. This is a sedimentary soil and was probably originally derived from the decomposition of basaltic material. The Boise loam, another important soil type, occurs on the mesas and slopes of terraces south of Boise River. The surface soil is a sandy loam underlain by loam which sometimes grades into clay loam and is underlain at about 2 feet with sandy loam or fine sand which often forms a hardpan. The Deer Flat sandy loam to a depth of 2 feet is a red sandy loam with some coarse sand. The subsoil is light in texture and is readily permeable to water. The Caldwell sandy loam is an alluvial soil of recent origin, consisting of sandy material sometimes containing gravel. Much alkali carbonate occurs in this soil.

Hardpan is quite generally found in the central and eastern parts of the area. Except along the slopes of terraces and drains it does not occur on the surface, and there are usually several layers of it, the depth of the first layer varying from a few inches to about 5 feet. As the subsoil water is usually some distance below the surface it is somewhat difficult to account for the presence of hardpan in the Boise Valley. Since hardpan in this area invariably occurs at the change downward, from a heavier to lighter soil, it is fair to assume that an important factor in its origin is the mechanical characteristics of the soil itself. The moisture in descending through the soil dissolves a part of the more soluble salts and a part of the carbon dioxide gas, more plentiful in the soil than in the atmosphere. This forms a solution which is capable of dissolving a much larger quantity of calcium and magnesium carbonates than water free from carbon dioxide can dissolve. When this solution descends through the heavier or finer grained soil, the soil spaces, being small, will be practically filled and a chemical action will take place by which the calcium and magnesium carbonates in the soil will be dissolved, forming the hydrogen carbonates of these bases, but in the lighter soil the air spaces and the surface of the individual soil grains are larger and as the solution passes through it will not be sufficient to fill all air spaces. There will then result a lowering of the partial pressure of the carbon dioxide and a partial liberation of this constituent of the solution, with the result that part of the calcium and magnesium hydrogen carbonates in the solution will be changed to the more insoluble normal carbonates of these bases, and will form as a precipitate around the soil grains. This occurring at the change from a heavier to a lighter soil texture, will give rise to the formation of the hardpan in the lighter rather than in the heavier soil, as is actually the case. This same explanation would hold if the subsoil water were near enough to the surface to reach it by capillarity, bringing with it the dissolved carbon dioxide and soluble salts from below, and there is no doubt that the process is actually reversed after heavy rains or excessive irrigation.

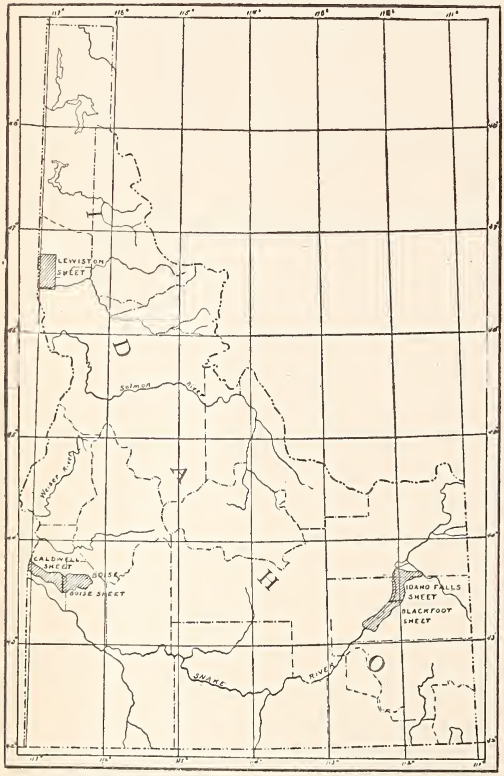

FIG. 6.—Sketch map showing location of areas in which alkali has been studied in Idaho.

The greater part of the Boise area was found to contain less than 0.20 per cent of salt in the first 6 feet, but there were some minor exceptions. Between Meridian and Caldwell there were a number of bare spots in sagebrush land. The absence of vegetation was due to the high salt content of the soil and the physical conditions of the soil itself. Determinations of the salt found in these spots showed that the mean percentage of salt was usually from 0.40 to 0.60 per cent in the first 6 feet. The maximum was usually in the first or second foot, the salt content then decreasing with only a small quantity in the fifth or sixth foot. The distribution of the salt in the soil depends upon the influence of the subsoil water and surface irrigation. On the uncultivated uplands the maximum was found either in the fourth or fifth foot, while in the lower areas in the alluvial soils the maximum was found in the surface foot, with generally but a small percentage farther down. The relation of the various components of the salt to one another also varies with the condition of the subsoil water.

The highest percentages of salts found in the bench soils, except in surface accumulations, were found on or near the slopes of drains and bluffs, where the soil moisture first approaches the surface, carrying with it the salt in solution. In the bench lands the soil moisture and subsoil water carrying the salt in solution naturally gravitate toward the lower creek and river bottoms. This process, going on continually, raises the water table in these lowlands. As the soil has good natural drainage in these places the water in the lowlands constantly carries the salt away, leaving only as much salt in the soil as the water itself is capable of giving to it, which depends upon the concentration of the subsoil water. In the bottoms the subsoil water is near the surface, being found at a depth of from 3 to 7 feet when the examination was made. This is near enough to favor capillary movement of the water toward the surface, and accounts for the surface deposits found there, as well as for the fact that the maximum salt content is in the surface foot. Below this depth there is little salt. On the virgin soils of the bench lands the moisture does not reach the surface and consequently the salt does not, the maximum being found either at the lower limit of the downward movement of the surface moisture or near the upper limit of the capillary movement of the subsoil water.

In but few places on the bottom lands did the total salt content in the first 6 feet exceed 0.40 per cent, most of which was in the surface foot, from one-fourth to five-eighths being alkali carbonates. As a rule, chlorides and sulphates were not present in large quantities in the alluvial soils, the salt consisting principally of carbonates and hydrogen carbonates. On the bench lands the sulphates and carbonates were more abundant, forming a large portion of the total salt content. The reason for a smaller percentage of sulphates and chlorides in the river soils than in the bench lands, the same concentration considered, is undoubtedly due to the fact that these constituents have either been carried away in the process of formation of the river soil, or if they have ever been present in large quantities have been dissolved out and carried away by irrigation water or subsoil water, or both. The alkaline carbonates were present in much larger quantities in the surface foot in the river-bottom soils than in the bench soils, while the sulphates and chlorides have been washed out of the river soils by the movement of the subsoil water and have not been replaced as rapidly with the salts from the subsoil or from the waste water from the bench lands. The alkaline carbonates were found to be constantly increasing in the river soils. The source of these salts is doubtless the seepage water from the bench lands, which contains a little alkali carbonate and much hydrogen carbonate. The latter reaches the surface by capillarity, there to lose some of the carbon and form alkali carbonates.

Chemical analyses of soluble salts in alkali soils.

Constituent.	5824. W. cen. sec. 20, T. 5 N., R. 5 W. Subsoil of Deer Flat sandy loam 24 to 60 inches.	5838. Cen. sec. 15, T. 4 N., R. 4 W. Soil of Caldwell sandy loam 0 to 12 inches.	Standardization solution of Boise Valley.	X. Alkali, surface deposit.	5852. Alkali, surface deposit.	5851. Alkali, surface deposit.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.05	0.18	Tr.	0.37	1.75	0.17
Magnesium (Mg)	2.05	.18	0.31	.47	1.24	.09
Sodium (Na)	15.22	31.25	34.46	30.58	29.02	34.70
Potassium (K)	20.51	5.23	1.05	2.28	.97	.92
Sulphuric acid (SO_4)	8.88	12.31	31.71	48.74	54.91	10.04
Chlorine (Cl)	40.87	3.85	6.29	6.63	11.53	3.38
Bicarbonates (HCO_3)	10.42	23.35	9.58	6.93	.53	26.88
Carbonic acid (CO_3)	....	33.65	16.29	4.00	.05	23.69
Phosphoric acid (PO_4)	....	....	.31	Tr.	....	.13
Nitric acid (NO_3)	....	....	....	....	....	Tr.
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	6.83	.64	Tr.	1.28	5.93	.57
Magnesium sulphate ($MgSO_4$)	5.10	.82	1.53	2.20	6.15	.41
Magnesium chloride ($MgCl_2$)	3.93	....	....	....	....	....
Potassium chloride (KCl)	38.98	8.08	1.98	4.34	1.84	1.75
Sodium chloride (NaCl)	30.79	....	8.84	7.54	17.56	4.19
Sodium bicarbonate ($NaHCO_3$)	14.37	31.27	13.20	9.55	.72	36.97
Sodium sulphate (Na_2SO_4)	....	16.54	45.13	8.01	67.70	14.12
Sodium carbonate (Na_2CO_3)	....	41.55	28.78	7.08	.10	41.75
Potassium bicarbonate ($KHCO_3$)	....	1.10	....	....	....	.42
Sodium phosphate (Na_3PO_4)	....	....	.54	....	....	....
Total salt content	1.17	2.17	[a]3.529	14.83	20.25	43.22

[a] Grams per 100 cubic centimeters.

The reclamation of the alluvial soils will depend upon the removal of the underground water, since this is the principal cause of the formation of the black alkali in these areas. As there are many natural sloughs leading to the river that could be used as main drains, the reclamation of these areas would not be difficult. In the case of the small black alkali spots it is different, but deep cultivation and generous applications of irrigation water would do much toward their amelioration.

HANFORD AREA, CALIFORNIA.

This area was surveyed in 1901 by Macy H. Lapham and W. H. Heileman. The Hanford area consists of 216 square miles, lying near the geographical center of the San Joaquin Valley. It is agriculturally important, because of its production of raisin and wine grapes and deciduous fruits, and also its production of grains, hay, and dairy products.

The region consists of broad and extensive delta deposits laid down by the waters of Kings River and its tribuatries, spread over the valley floor and sloping toward the southwest, with a fall of some 3 or 4 feet to the mile. The natural slopes are so gradual and uniform as to be hardly sensible, and the area is cut by a network of blind sloughs and former stream channels. Natural drainage is at an advanced stage, the beds of the frequently shifting streams being rapidly filled with sediments. When not protected by artificial levees, the land adjacent to the Kings River bottoms is subject to overflow during periods of flood.

The prevailing soils are sands and sandy loams, deposited as broad, nearly level areas or as slightly elevated irregular bodies, elongated strips marking former stream courses. They are generally of medium to fine texture, frequently very micaceous, of open, porous structure, and are made up largely of granitic material. In the types occurring along the northern and northeastern boundaries of the area there is a liberal admixture of volcanic material rich in the common alkali salts. It is from these volcanic ash soils, locally known as the "white-ash lands," which are strongly impregnated with alkali and occupy extensive areas to the northward from Kings River, that the soils lying to the southwest—which are of a more porous structure and in themselves not originally impregnated with alkali salts—receive their drainage. The evils of this unfortunate condition are apparent, the alkali in these soils spreading and encroaching more and more upon the valuable fruit, vineyard, and grain lands of the central part of the area.

The system of irrigation as practiced in the Hanford area consists, essentially, in the saturation of the subsoils by seepage or subirrigation. Water is rarely, if ever, applied to the surface of the soil. The main canals and larger tributaries generally follow the higher sandy ridges. From these the water is led in small ditches or furrows elevated slightly above the surface of the fields. These waterways are constructed upon a very slight grade maintained by frequent check weirs. During the early spring months the canals and distributing ditches are filled to their full capacity and the water maintained at a high level. This results in a rapid movement of water by lateral percolation through the porous subsoils until these are completely saturated and the water table is raised nearly to the surface. This process is allowed to continue until the surface soil of the fields is thoroughly moistened. In this manner the water table of the heavily irrigated part of the area has been raised in general 10 or more feet. As the moisture is removed from the soil surface by evaporation it is constantly supplied from below by the saturated, porous subsoils, through which capillary movement is unusually rapid. By lateral and upward movement the readily soluble alkali salts are thus removed from heavily impregnated subsoils, transported by percolating waters, and brought to the soil surface, where they are deposited at the immediate surface or within the root zone of crops. Even when occurring in but minute and limited quantities throughout the subsoils they may thus become concentrated at the surface and work extreme injury. The irrigating waters of the area are of excellent quality and free from any injurious amounts of alkali salts, and it is from the soils themselves, and mainly from the concentration of salts by evaporating soil waters that the damage originates. That the injury has not spread more rapidly is largely due to the checking of the otherwise rapid rate of evaporation from the soils by frequent cultivation and by the maintenance of an excellent state of tilth upon most of the vineyard and orchard lands. Owing to the abundant water supply and a cheap, simple, and effective means of application there is a tendency in the Hanford area toward the use of excessive quantities of water for irrigation purposes.

At the time the alkali survey of this area was made, during the early summer of 1901, nearly one-half of the lands were more or less affected by an excess of alkali salts, which were rapidly spreading in extent and increasing in concentration.

In the northern and northeastern parts of the area, chiefly upon the so-called "white-ash lands," previously mentioned, the conditions were very bad, several square miles having been abandoned for agricultural purposes, save as they furnished a scanty pasturage. Natural drainage is here defective, and the alkali salts occur in concentrated form both in the surface and in the alkali-lime-carbonate hardpan of general occurrence in the subsoil. Extending in a southwesterly direction across the area and in the path of the natural drainage slopes were a large number of small patches, chiefly upon the porous, fine micaceous land, that were unfit for crops. With the exception of a few irregular bodies the bottom lands in the vicinity of Kings River were free from alkali salts in injurious amounts. The central and western parts of the area were generally free from alkali in extreme concentrations, but contained many small and irregular patches over which the salts occurred in such quantities as to more or less reduce production. Since these parts of the area are largely devoted to fruit culture, the spread of the salts has been less rapid than upon those sections devoted to some crop in which cultivation plays a less important part.

The common alkali salts of the area consist principally of sodium and magnesium sulphates with about 24 per cent of the extremely injurious sodium carbonate, or black alkali, and about 10 per cent sodium chloride. The black alkali is of general occurrence whenever the total salts reach the more concentrated limits and at once makes itself known by the compact, puddled condition of the soil and in the inky black appearance of the drainage and seepage waters collected in pools.

In the following table is given the average composition of the alkali in the soils of the Hanford area:

Chemical analysis of composite sample of alkali soils from Hanford area.

Ions.	Per cent.	Conventional combinations.	Per cent.
Calcium (Ca)	0.45	Calcium sulphate ($CaSO_4$)	1.53
Magnesium (Mg)	.36	Magnesium sulphate ($MgSO_4$)	1.78
Sodium (Na)	33.68	Sodium sulphate (Na_2SO_4)	52.52
Potassium (K)	.79	Potassium chloride (KCl)	1.51
Sulphuric acid (SO_4)	37.98	Sodium chloride (NaCl)	9.35
Hydrochloric acid (HCl)	6.38	Sodium carbonate (Na_2CO_3)	23.87
Carbonic acid (CO_2)	13.50	Sodium bicarbonate ($NaHCO_3$)	9.44
Hydrogen carbonic acid (HCO_3)	6.86		
Total	100.00	Total	100.00

On land containing less than 0.20 per cent of alkali all crops suited to the soil type do well. Where the land contains from 0.20 to 0.40 per cent of salts, most crops can be grown, although when the major limit (0.40 per cent) is reached certain crops, notably alfalfa, most tree fruits, grapes, and grain crops, begin to suffer. However, pears and figs, if the land be well drained, and beets, onions, sorghum, and some grasses, including alfilaria and sporobolus, will grow quite well on such land. On land containing from 0.40 to 0.60 per cent of alkali few crops will survive; only the salt grasses, alkali heath, and various weeds will be able to subsist. No cultivated plants, except a few pear trees, were found on land containing 0.60 per cent of alkali. Land containing from 0.60 to 1 per cent is practically worthless. Pear trees may grow, if well started and if all the alkali is in the first 2 feet, but in general, aside from some pasturage, land of this class has little agricultural value. Land containing from 1 to 3 per cent of alkali is so salty that many of the alkali grasses will not grow upon it.

The acreage of land carrying the various percentages of alkali is as follows:

Areas of alkali land, classified according to degree of salt content.

Grade of alkali soil.	Acres.	Per cent.
Less than 0.20 per cent alkali	82,100	58.4
From 0.20 to 0.40 per cent alkali	40,340	29.2
From 0.40 to 0.60 per cent alkali	7,720	5.6
From 0.60 to 1 per cent alkali	1,770	1.3
From 1 to 3 per cent alkali	6,310	4.5
Total	138,240	....

Under the conditions of irrigation and management existing at the time of the survey, the more or less complete ruin of at least a large portion of the area seemed probable, and the gradual abandonment of tracts to alkali-resistant crops, then to pasture, and finally to complete loss, seemed a certainty.

Not only are excessive amounts of water applied to the land in irrigation, but the process of saturating the subsoils and keeping the lands continually wet is hastened by artificially damming the slough channels—the natural drainage outlets—in order further to raise the water table. The efforts of nature herself in providing natural drainage outlets have thus been perverted and turned into positive injury. Yet few sections possess greater natural facilities for freeing the soils from noxious alkali salts and maintaining them in a productive condition.

With the adoption of remedial measures in opening the natural drainage channels by making a few artificial cuts, by greater economy in the use of irrigation waters, and by the practice of the more expensive, but less injurious, methods of irrigation by surface flooding nature would herself repair much of the injury.

Upon some of the heavily impregnated alkali soils of the area the opening of drainage canals and the laying of tile-drains at frequent intervals would be necessary.

LOWER SALINAS VALLEY, CALIFORNIA.

In 1901, Macy H. Lapham and W. H. Heileman made a survey of the lower Salinas Valley. This area covers the Salinas Valley from King City northward. Its chief agricultural importance arises from its production of grains, sugar beets, potatoes, beans, and apples. The summer climate of this area is marked by high temperatures, low relative humidity, and strong daily winds increasing in velocity with their progression up the valley, these conditions promoting excessive evaporation from the soil surface. The soils and subsoils of the area are, however, capable of retaining large quantities of water in spite of these influences.

The soils naturally fall into three classes—upland soils, valley soils, and recent sedimentary soils—each of which is quite distinct in its typical form and often separated from the others by marked topographic features. The soils are mainly of alluvial or colluvial origin and are derived by weathering and waste of a complex variety of rocks of the surrounding mountains. In texture they range from incoherent sands to heavy and sticky adobes.

The water supply derived from the streams of the area is inconstant and is limited during dry seasons, while that derived from pumping from an underground source is costly. Irrigation is practiced in general upon the heavy adobe lands of the valley, devoted to sugar-beet culture and to the raising of limited quantities of alfalfa and special crops. The higher slopes devoted to the growing of grains are unirrigated. The character of the irrigation waters is generally good.

Many of the waters from the surface wells in the upper part of the valley carry in solution large quantities of the common alkali salts, indicating that these are present in the deeper subsoils. Owing to the limited extent of irrigation, good natural drainage, and depth to water table, these alkali salts have not as yet become concentrated within the root zone of the crops. In the lower part of the valley the alkali salts frequently make their appearance in slight crusts in local valley depressions, and in the vicinity of the open sloughs, of frequent occurrence in the lower valley. They are, however, rarely concentrated enough to affect the most sensitive field crops. Examination reveals the presence of small quantities of alkali salts to great depth in the subsoils. In the vicinity of Monterey Bay and its tidal marsh lands, which extend as small bodies for some distance into the area, the soils are saturated with strong solutions of marine salts. Some of these tidal lands have been partially reclaimed for grazing purposes by a system of tidal flood gates and shallow trenching and cultivation.

While the present alkali condition of the Salinas Valley is a matter of but slight importance, observations indicate that in the aggregate a large quantity of the common alkali salts occur in the valley subsoils, and that in the event of future extension of irrigation and the use of large quantities of water, concentration may occur in certain areas of restricted drainage to such an extent as greatly to damage crops. The first appearance of salts in injurious quantities should be the signal for immediate drainage of the affected districts.

VENTURA COUNTY, CAL.

In the summer of 1901 a soil survey was made by J. Garnett Holmes and Louis Mesmer of the agricultural lands of Ventura County, Cal. This part of the county is included in the valleys and combined deltas of Ventura and Santa Clara rivers. These lands are bounded on the southwest by the Pacific Ocean and on the land sides by rough hills or mountains.

There is an average rainfall of about 15 inches, all occurring during the winter and early spring. The climate is semitropical. There are frequent variations from the normal of 15 inches rainfall, but with careful cultivation there is rarely an entire failure of crops on unirrigated lands. In fact, comparatively little irrigation is practiced, most of the farmers depending wholly upon rainfall for moisture for their crops.

The soils of the delta are principally sand, sandy loam, and loam, all of which are leachy and take water readily. Potentially the valleys and delta are well supplied with water for irrigation. The soils are such that if they receive an amount of water during the winter months equal to 15 inches of rainfall, a good yield of the principal crops grown—Lima beans and sugar beets—may be obtained without further irrigation. Irrigation while the crops are growing increases the yield, but paying crops may be obtained from winter irrigation alone. Artesian water may be obtained at reasonable depths for all the lower part of the delta, which would furnish a constant supply for summer irrigation. Santa Clara and Ventura rivers drain a vast area that is for the most part practically untimbered. During the flood or winter season these streams are raging torrents, but shortly after the rains cease they become almost dry. All this summer flow is used for irrigation, but irrigates only a very small part of the lands. Summer irrigation is applied by the furrow method. A few practice summer irrigation from artesian wells.

All the lower part of the delta extending along the coast has a water table that is only from 4 to 10 feet below the surface at the driest time of the year. During the rainy season water stands in many small lakes along the ocean side, which are separated from the sea only by low dunes of beach sand.

The survey made in 1901 showed about 9,000 acres of these low, moist lands so filled with alkali as to produce almost no cultivated crops. Since shallow-rooted annuals are principally grown, fluctuations of the water table are of little moment, the real problem of the area being to reclaim these alkali lands, so that crops may be grown. The soils are nearly all quite sandy and leachy, and nature has supplied main drainage ways for much of the affected lands. Broadly speaking, flood irrigation, with careful cultivation, will reclaim the lands. A few drains will have to be installed, but the principal innovation must be irrigation. Enough water annually flows to the sea during the high-water season to flood heavily the entire delta. The preparation of the lands for winter flooding, and the construction of canals to divert these flood waters to the lands, with adequate drainage provided for, would permit heavy flooding during the winter months. This would supply sufficient moisture for fair summer crops and at the same time reclaim the lands from alkali. The development of artesian water would allow furrow irrigation during the summer months and the production of maximum crops. The water of both the river and artesian wells is of good quality for irrigation and entails no risk in its use.

Appended is a table of analyses of the salts of the area:

Chemical analyses of alkali soils and crusts.

Constituent.	East side of Saticoy	4795. Lot 48 E. of ranch house.	One-eighth mile W. of Woods and Leguma roads.	4792. 100 yards S. of experiment station house.	4662. 2 miles SW. of ranch house.	Near mouth of Santa Clara River, S. side.	4798. 50 yards E. of pond No. 2.	One-quarter mile W. of Hueneme slough.	Standardization solution.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	0.59	1.46	1.66	1.31	2.42	4.34	1.29	1.78	0.39
Magnesium (Mg)	5.88	6.47	3.51	5.32	5.68	2.41	7.61	1.34	4.76
Sodium (Na)	22.22	20.55	19.88	22.96	18.26	25.46	20.84	32.92	25.28
Potassium (K)	.82	1.42	1.42	.99	5.48	.99	1.10	1.54	.58
Sulphuric acid (SO_4)	62.05	59.39	61.60	57.38	54.62	50.35	43.02	12.98	56.08
Chlorine (Cl)	7.38	10.16	10.53	11.19	13.30	14.98	25.43	49.19	11.91
Carbonic acid (CO_3)	.03	....	.18	....	.27	....	.71	....	....
Bicarbonic acid (HCO_3)	1.03	.64	1.25	.85	....	1.47	....	.25	1.00
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	2.81	4.94	5.66	4.42	8.21	14.77	4.40	6.04	1.37
Magnesium sulphate ($MgSO_4$)	29.24	32.08	17.40	26.52	28.13	11.94	37.72	6.67	23.64
Sodium sulphate (Na_2SO_4)	53.53	44.78	56.99	49.21	29.09	46.14	14.52	5.11	53.75
Potassium sulphate (K_2SO_4)	....	....	....	....	12.20	....	....	....	....
Sodium chloride (NaCl)	10.81	14.65	15.25	17.00	21.91	23.24	40.34	78.90	18.77
Potassium chloride (KCl)	1.51	2.70	2.72	1.88	....	1.89	2.08	2.94	1.10
Sodium carbonate (Na_2CO_3)	.69	....	.26	....	.47	....	.94	....	....
Sodium bicarbonate ($NaHCO_3$)	1.41	.85	1.72	1.17	....	2.02	....	.34	1.37
Per cent soluble	43.45	28.13	38.52	28.23	19.93	16.43	25.48	41.71	6.70

Chemical analyses of alkali soils and crusts.

Constituent.	4793. 250 yards S. of experiment station slough.	4796. Post 44.	One-fourth mile W. of Patterson ranch house.	Lot 56, O. la Colonia ranch.	4794. Dunes W. of Post 49.	4791. Pond W. of Post 25.	4665. One-half mile E. of ranch house.	4 miles E., 1 mile N. Hueneme.	2 miles E. of Hueneme.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	1.39	1.20	1.01	0.91	0.89	0.86	1.54	1.34	3.07
Magnesium (Mg)	6.38	5.59	5.92	3.87	6.66	7.78	7.63	2.37	2.11
Sodium (Na)	20.33	21.59	25.84	25.11	20.42	19.13	13.13	27.38	25.46
Potassium (K)	.77	1.17	.58	.82	1.11	.50	8.26	.57	1.14
Sulphuric acid (SO_4)	67.41	65.30	62.51	64.16	65.49	66.74	63.92	61.89	60.49
Chlorine (Cl)	2.72	3.72	3.78	4.32	4.63	4.65	5.28	6.02	6.34
Carbonate (CO_3)	....	....	....	.08	....	....	.21	....	.12
Bicarbonate (HCO_3)	1.00	1.43	.36	.73	.80	.35	....	.43	1.27
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	4.71	4.07	3.43	3.10	3.00	2.92	5.23	4.57	10.42
Magnesium sulphate ($MgSO_4$)	31.59	27.69	29.36	19.55	33.02	38.55	37.81	11.75	10.43
Sodium sulphate (Na_2SO_4)	57.51	59.64	60.24	68.84	54.79	50.19	29.45	72.92	67.38
Potassium sulphate (K_2SO_4)	....	....	....	....	....	....	18.40	....	....
Sodium chloride (NaCl)	3.33	4.39	5.36	5.79	5.98	6.92	8.71	9.06	7.66
Potassium chloride (KCl)	1.47	2.24	1.11	1.57	2.12	.96	....	1.10	2.17
Sodium carbonate (Na_2CO_3)	....	....	....	.14	....	....	.37	....	.19
Sodium bicarbonate ($NaHCO_3$)	1.39	1.97	.50	1.01	1.09	.46	....	.60	1.75
Per cent soluble	36.05	37.56	49.25	63.85	57.64	70.96	15.06	28.67	23.28

The analyses given in the above tables show a decided similarity in the salts of the crusts and the salts of the river and the artesian belt fed from the river. This justifies a presumption that the alkali has been brought into the valley in the waters of the river. The only possible local source would be the ocean, but there is nothing in the analyses of any of these samples that in any way indicates such an origin. The alkali, when present in harmful quantities, has been concentrated by long-continued evaporation of moisture at the surface of the soil. This moisture is furnished by capillarity whenever the subsoil water rises above a certain depth—a depth measured by the power of attraction latent in the several soil types. Under most of these soils the subsoil water is sufficiently close to the surface to make such connection possible during the greater part of the year. Whenever there is an accumulation of alkali of any kind in sufficient quantity to damage crops there is found associated with it this high water table, and usually the alkali is in a soil of great capillary power.

In the following table is shown the relative extent of the different grades of alkali lands.

Areas of different grades of alkali lands.

Grade of alkali soil.	Acres.	Per cent.
Less than 0.20 per cent	129,619	84.3
From 0.20 to 0.40 per cent	8,742	5.7
From 0.40 to 0.60 per cent	3,808	2.4
From 0.60 to 1 per cent	2,931	1.9
From 1 to 3 per cent	4,122	2.7
Over 3 per cent	4,582	3.0

The agricultural part of southern California proper is made up of the San Fernando, San Gabriel, and San Bernardino valleys and the Coastal Plain, extending from Santa Monica to the hills southeast of Newport in Orange County. All of this region, except a part of the San Fernando Valley, has been surveyed by the Bureau of Soils, and maps and reports of the same have been published. In the fall of 1900 the first work was done about Santa Ana by J. Garnett Holmes, and the reports and maps were published in the annual report of the Bureau for that year. In the spring of 1901 the San Gabriel Valley was also surveyed by Holmes. In the winter of 1902–3 Louis Mesmer surveyed the Coastal Plain west of the Santa Ana area and a part of the San Fernando Valley. In the early spring of 1904 the San Bernardino Valley was surveyed by Holmes, and the reports and maps of these various areas have been published in the annual reports of the Bureau for the respective years in which they were surveyed.

Each district has peculiar conditions, although the problems of the valleys are quite similar, and the Coastal Plain may be considered as a whole. For the sake of convenience, however, each valley and the Coastal Plain will be considered separately.

SAN GABRIEL VALLEY, CALIFORNIA.

In the report made in 1901 the general conditions of this valley are discussed, so that it will be necessary here simply to give a résumé of a part of this general discussion before proceeding to discuss the specific problems outlined above.

The San Gabriel Valley lies just along and south of the Sierra Madre range of mountains. It is cut off from the Coastal Plain by a long, low range of foothills known as the Coast Range. The San Gabriel River, which rises in the Sierra Madre to the north, divides the valley into about equal parts and passes through a narrow pass cut through the Coast Range at the southern side of the valley. The rainfall increases rapidly from the southern side of the valley toward the north, where the Sierra Madre Range causes an increased precipitation of nearly 50 per cent, the range being from 10 to nearly 20 inches.

Nearly all the soils of the valley are composed of rather coarse material, constituting the wash from the granitic mountains on the north. Because of the loose, porous nature of the soils much loss by seepage occurs in the irrigated fields, and much of the water of the San Gabriel River and the numerous small streams that come down from the mountains seeks underground passage through the valley. The only outlet for this seepage water is through the San Gabriel River pass in the Coast Range. This pass is very narrow, so that the seepage water is forced near the surface over quite a large area in the southern part of the valley. During the rainy season much of this low, swampy land has received floodings until recent years, when dikes were constructed and the lands have since been used for truck farming.

At the time of the survey in 1901 a few alkali spots were beginning to show throughout these moist lands, but in no case was the total percentage for the surface 6 feet sufficiently high to kill ordinary crops. The greatest damage done by either the seepage water or alkali had occurred in some of the early walnut groves, which had been injured by the rise of the water table and a consequent "drowning" of the roots. Where the water comes so close to the surface that drains of economical installation will lower and control it such drains will be of great value. As soon as alkali menaces the crops grown arrangements should be made to raise water by pumping, and the whole surface should be heavily flooded. It may be possible to construct ditches to utilize flood waters, which, if of frequent occurrence, would tend to wash out the accumulations of salts. In the northern part of the valley the rainfall is probably sufficient to wash out the surface accumulation that comes from furrow irrigation.

On the whole, the valley was remarkably free from alkali and damage from shallow water table. The southern part of the valley and a small area near Pomona were the only affected districts. Occasional surface flooding and possibly a small amount of drainage are all that is necessary to maintain the conditions existing at the time of the survey.

SAN BERNARDINO VALLEY, CALIFORNIA.

The soil survey of San Bernardino and a part of San Jacinto Valley was made in the early spring of 1904. In this survey only a small number of alkali areas were encountered. The soils and climate of the area are very similar to those of the San Gabriel Valley.

Prior to irrigation a large area of land near Chino, in the San Bernardino Valley, was continually moist and swampy, being occasionally overflowed by small streams from the mountains on the north. Since irrigation began many wells have been sunk in the gravel to the north, and all the streams have been diverted, rendering these swamp lands sufficiently dry for cultivation. Wells have been put down to develop water for the land that was originally a swamp, and now many acres are irrigated. Irrigation on the high land above Riverside has caused some of the land in that colony to be swamped and the citrus trees to be killed. The total acreage, however, that has been thus affected by swamping is very small. The major part of the seepage reaches the deep cut of Santa Ana River in the form of springs, and does no damage to crops.

In San Bernardino proper the only problems thus far arising are to reclaim and prevent the spread of alkali lands near Chino and to make useful the land damaged by seepage in Riverside. The problem near Chino may be solved simply by securing water and flooding heavily the lands showing damage from alkali. The seepage lands in Riverside should be drained and sown to alfalfa or truck crops. One or two heavy floodings will be sufficient to wash out such accumulations of alkali as have occurred since the seepage water killed out the orange trees.

In the San Jacinto Valley there are some quite large areas of alkali lands. Pumping is quite general in the valley and has already resulted in the water table being generally lowered. This pumping is the only available source of water for irrigation, and if it be extended to furnish water to irrigate the alkali land the water table will be sufficiently lowered to cause little damage. Heavy floodings should reclaim the land from alkali and permit the growing of such crops as are suited to the valley.

SAN FERNANDO VALLEY, CALIFORNIA.

When the Los Angeles sheet was surveyed in 1903, a small part of the San Fernando Valley was included, but no alkali was encountered. This valley is almost entirely free from alkali, and extended pumping operations that are being prosecuted will no doubt keep the water table below the danger point.

COASTAL PLAIN OF SOUTHERN CALIFORNIA.

The Coastal Plain proper of southern California is included in the quadrangle of which Los Angeles, San Pedro, and Newport Bay form three corners, the fourth being about 5 miles east of Santa Ana. It is bounded on the southwest by the Pacific Ocean; on the northeast by the Coast Range of hills, which also divides it from the valleys described above, and on the southeast and northwest by spurs of the Coast Range which extend to the ocean. The climate is semiarid and semitropical. The rainfall is sufficient in normal years to grow fair crops of winter grain without irrigation, and for irrigated crops is a great aid in washing down surface accumulations of alkali and starting the crops when sown. The soils, except in the immediate vicinity of the Coast Range and other hills, are alluvial, having been deposited from the waters of the San Gabriel, Santa Ana, and Los Angeles rivers. As a rule they are leachy, sandy, and easily cultivated, the exceptions being the silt loams and adobes, the latter coming principally from the weathering of shales in the Coast Range.

Water for irrigation comes from the above-named rivers and a few small creeks, from pumping, and from artesian wells. Extending along the coast is an artesian belt. Land in this belt was kept continually moist even before irrigation began by springs and overflow waters from the rivers. Since the settlement of the region the greater part of the water of the rivers has been diverted at higher levels for irrigation, and a few drainage ditches have been installed in this moist area. Nearly all the land has thus been reclaimed from its swampy condition and planted. Prior to any agricultural activities there were alkali areas surrounding the swamps and in the places affected by tides. Before being cleared the annual floods washed the lands, and a dense growth of vegetation prevented excessive evaporation from the surface. After having been cleared and cropped, the lands have been left for a part of each year in a barren condition, and subirrigation has been the principal source of supply of moisture. Irrigation on the higher lands has brought the ground water nearer the surface over all the lands surrounding the once swamped area, with a consequent increase of the subirrigated area. As in all cases where subirrigation is practiced, the tendency has been toward the accumulation of alkali at the surface. In this way hundreds of acres of vines and fruit trees that were planted near the swamp lands in the early history of the country have been killed. As irrigation has been extended to the higher lands the water table, because of local subformations, has been in some instances raised to such an extent that older deep-rooted trees have been injured by the rise of the water table. The English walnut is largely grown upon the sandy Coastal Plain soils. In such soils, if there be nothing to prevent, this tree sends its roots to great depths and is the first to suffer from a rise of the water table. Trees have been noted that were suffering with the water table 12 to 15 feet below the surface. Trees planted upon soils having a permanent water table much nearer the surface than this are not injured, so that new orchards planted upon the areas affected, which will adjust their root systems to the high water table conditions, may be very successful where the old trees have died.

The development of sufficient water to flood all subirrigated lands and the extension of the present drainage ditches to reach all lands that have such a high water table as to be cut by the ditches would rid the soil and subsoil of surplus water. A few heavy floodings, after thoroughly leveling the lands, and the exercise of care to prevent evaporation from the surface should sufficiently sweeten the lands to permit the growing of profitable crops. Persistent flooding and careful cultivation should then keep the lands sufficiently free from alkali to permit continued cultivation on a profitable basis.

Alkali found on the Coastal Plain is nearly all of the white variety, principally the sulphate and chloride of sodium. Near the coast on lands affected by tides the chlorides predominate, while farther back the greater part of the alkali is composed of the sulphates.

GRAND FORKS AREA, NORTH DAKOTA.

The survey of the Grand Forks area was made during the field season of 1902, by Charles A. Jensen and N. P. Neill. The area is situated in Grand Forks County, one of the eastern tier of counties of North Dakota, and covers an area of 314 square miles. The area comprises part of the Red River Valley. The annual rainfall is approximately 20 inches, usually so distributed as to furnish moisture for crop purposes during the growing season. Occasionally, however, a season of drought occurs, when crops are practically a failure. The surface of the country is generally quite level, with few marked benches or terraces. Much of the area comprises a portion of the former glacial Lake Agassiz. The soils are mainly sandy loams, gravelly loams, and clay loams composed of slightly modified lacustrine deposits, although there are some soils that have been derived from the glacial drift surrounding former Lake Agassiz. Shallow wells generally contain less soluble salts than the deeper, and especially the flowing wells. The flowing wells contain from 420 to 1,430 parts of soluble salts per 100,000 parts of water, the salts consisting mostly of chlorides, with sulphates next. The deep and flowing wells generally contain less bicarbonates than the shallow wells.

In this area there is generally enough precipitation to prevent the salt in the subsoil from lodging permanently in the surface soil through capillary action, and the roots of crops commonly grown perhaps never reach deeper than 3 feet. Since irrigation is not practiced in the area, the vertical distribution of the salts is not affected artificially, and as long as the present method of farming continues there seems no probability that the salts in the subsoil will rise. In the lighter, well-drained soils there is practically no alkali to a depth of 6 feet. Injurious quantities of alkali were found in the Miami black clay loam and in the Fargo gravelly loam where it occurs in the valley proper. In the first 3 feet of these soils the average amount of alkali is more than 0.20 per cent, with even more in the first 6 feet. The worst alkali conditions were found in the northeastern part of the area. This includes most of the strictly lacustrine deposit soils. Two theories are suggested to account for the origin of the alkali. It may have reached the surface by the capillary movement of the salt-carrying deep-seated waters percolating the underlying drift or cretaceous shales, assisted by the natural pressure to which these substrata are subjected; or it may have been deposited with the lacustrine material by being in solution in the lake water or as being originally in the soil washed into the lake. Since it does not appear that the lake water ever reached a high state of concentration, the latter theory can probably be rejected.

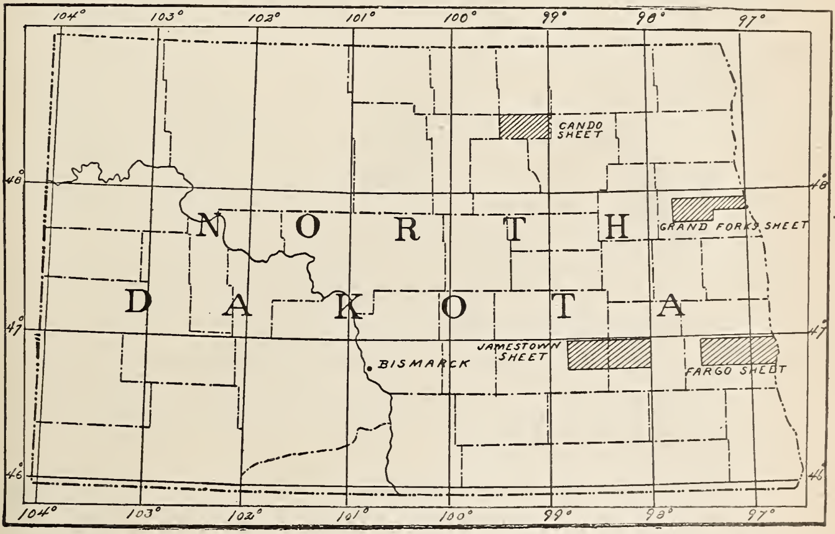

FIG. 7.—Sketch map showing location of areas in which alkali has been studied in North Dakota.

Sulphates largely predominate, with some chlorides, but not in large quantities. With but few exceptions the quantity of salt was found to increase downward. The maximum found was about 3 per cent in the dry soil, and in the worst alkali districts this quantity was found at from 3 to 6 feet. Black alkali was found, even in the presence of small amounts of sulphates, in both soil and subsoil.

Good crops of grain, flax, and millet were often found growing on alkali soils, even where the average amount of salt in the first 3 feet ranged from 1 to 3 per cent. This was due to the unequal vertical distribution of the alkali—the surface foot carrying but a small proportion of the total amount.

The following table, while not intended to define the exact salt conditions under which crops will or will not grow, shows at least conditions as found in the Grand Forks area:

Condition of growing crops in presence of different quantities of alkali.

Crops.	Condition.			
	Good crop.	Fair crop.	Poor crop.	Killed.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Wheat	0.30			0.56
	.39			.76
	.46			
Oats	.39	0.58	0.63	
	.46		.84	
	.51			
Barley	.31	.44	.70	
	.43	.46		
Flax	.32	.37	.52	.50
	.38	.55	.64	.86
Prairie and salt grasses	1.16	1.50		
	1.20	2.00		

There are of course different crop conditions with the same salt content in the surface foot of soil, as many factors enter into the discussion, such as late or early seeding, presence or absence of favorable amounts of moisture in the soil, etc. It should also be kept in mind that in every instance the salt content increased in lower depths, the third foot carrying more than 1 per cent of alkali in cases where good crops were growing.

To reclaim these lands they must be drained artificially, as the subsoil is too heavy to accomplish drainage otherwise. Under the present agricultural conditions it is doubtful if the expense involved in reclamation would be justified. Even in their present condition the alkali flats are valuable, as the native grasses growing on the greater part of them make very good hay when properly cured.

In the following table are shown the results of chemical analyses of a number of alkali soils and crusts:

Chemical analyses of alkali soils and crusts.

Constituent.	7460. ¼ mile E. of University; alkali crust.	7461. ¼ mile W. of NE. corner sec. 12, T. 151 N., R. 51 W., alkali crust.	7462. ¼ mile W. of NE. corner sec. 12, T. 151 N., R. 51 W., subsoil 12 to 36 inches.	7463. ⅛ mile S. of NW. corner sec. 6, T. 151 N., R. 50 W., subsoil 4 to 6 feet.	7464. ⅛ mile E. of SW. corner sec. 22, T. 151 N., R. 50 W., alkali crust.	7465. ¼ mile S. of NW. corner sec. 10, T. 151 N., R. 50 W., alkali crust.	7466. West center sec. 31, T. 150 N., R. 55 W., subsoil 12 to 36 inches.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Calcium (Ca)	6.74	5.83	16.82	13.31	1.76	7.34	24.56
Magnesium (Mg)	14.34	10.74	7.12	5.89	.81	14.24	1.55
Sodium (Na)	1.13	10.69	1.15	1.96	28.44	1.13	.94
Potassium (K)	1.42	.95	2.88	11.44	1.00	.59	1.55
Sulphuric acid (SO_4)	73.94	47.12	59.71	41.93	65.49	73.99	68.94
Chlorine (Cl)	.77	23.59	9.16	20.11	.64	1.56	.64
Bicarbonic acid (HCO_3)	1.66	1.08	3.16	5.36	1.86	1.15	1.82
Conventional combinations:							
Calcium sulphate ($CaSO_4$)	22.28	19.82	57.10	26.45	5.97	24.97	83.46
Magnesium sulphate ($MgSO_4$)	70.99	41.49	24.31	29.22	4.04	70.64	9.99
Sodium sulphate (Na_2SO_4)	2.55				85.91		2.35
Potassium chloride (KCl)	1.63	1.81	5.50	21.81	1.35	1.71	1.36
Sodium bicarbonate ($NaHCO_3$)	1.09	1.49	4.29		1.99	1.58	.72
Magnesium chloride ($MgCl_2$)		9.24	8.80				
Sodium chloride (NaCl)		26.15				1.70	
Calcium chloride ($CaCl_2$)				15.19			
Per cent soluble	10.79	15.50	3.82	2.24	12.96	12.52	5.27

BILLINGS AREA, MONTANA.

This area comprises about 107 square miles and was surveyed in 1902 by C. A. Jensen and N. P. Neill. Preliminary investigations were carried on near Billings in 1897 by Prof. Milton Whitney, while in 1898 Thomas H. Means made a study of the alkali and seepage waters of a section of land west of Billings. The results of the latter investigation were published in 1898 as Bulletin No. 14 of the Bureau of Soils under the title "The Alkali Soils of the Yellowstone Valley." The results of this earlier work will be included with the discussion of Jensen's report.

The area includes part of the Yellowstone Valley in the south-central part of eastern Montana. The valley consists of level areas, with higher terraces or benches bounded on each side by high continuous bluffs of cretaceous sandstone and shale.

The climate is semiarid, the valley having an annual rainfall of about 12 inches. This is not sufficient to grow crops, but materially aids irrigation. Agriculture was not extensively carried on until the building of the Northern Pacific Railroad in 1882. Since that time the development of the agricultural interests has been quite rapid.

The soils consist of clays, loams, and sandy and gravelly loams, with the heavy soils predominating. The soils are derived from the weathering of the Fort Benton shales and sandstones, modified and deposited by river action.

During the field work a large number of well, drainage, and spring waters were examined. All the samples contained a considerable quantity of salts in solution. The well waters were particularly impure, the salt content varying from 170 to 900 parts in 100,000 parts of water. From the examination it was found that the subsoil water is quite generally impregnated with alkali. The wells having the highest salt content are located in the level clay areas, where the soil texture is heavy to some depth, and in the alkali areas, where the subsoil water is near the surface. The better wells are located on or near the gravel terraces, as would be expected, the underdrainage there being comparatively good. Some of the springs found along the river bank and below the gravel terrace were much better than the wells, but as a general rule were too salty for use. This condition of the subsoil and drainage waters indicates forcibly both insufficient underground drainage and the existence of accumulations of salt in the subsoil. Such strongly alkaline solutions could hardly exist in all the wells were the underground drainage good, and the springs would not be so generally salty were there no accumulations of salt in the deep subsoil.

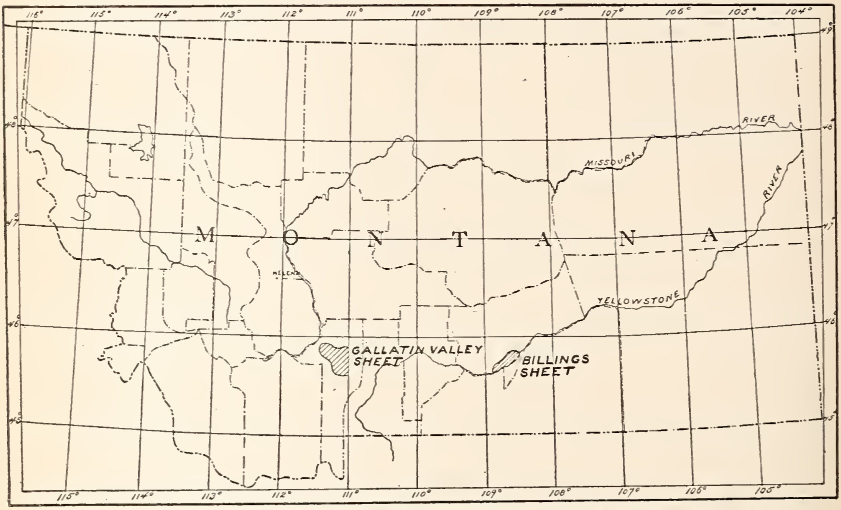

FIG. 8.—Sketch map showing location of areas in which alkali has been studied in Montana.

In the following table is shown the analysis of a sample of drainage water collected from about 2 miles southwest of Billings:

Constituent.	Per cent.	Constituent.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	7.11	Calcium sulphate ($CaSO_4$)	24.16
Magnesium (Mg)	4.84	Magnesium sulphate ($MgSO_4$)	24.01
Sodium (Na)	15.85	Potassium chloride (KCl)	1.92
Potassium (K)	1.01	Sodium chloride (NaCl)	2.23
Sulphuric acid (SO_4)	62.17	Sodium bicarbonate ($NaHCO_3$)	9.29
Chlorine (Cl)	2.26	Sodium carbonate ($NaCO_3$)	38.39
Bicarbonic acid (HCO_3)	6.75	Total solids, parts per 100,000	681.5

The greatest quantity of alkali was found in the heavy clay and loam soils. Alkali was not found, however, in all of the clay soils, as some have a light subsoil which gives good underdrainage. But wherever the clay extends to a depth of 6 feet or more, alkali is found. The vertical distribution of the alkali varies, being governed by the texture of the soil and subsoil and the position of the underground water. In virgin alkali clay areas the distribution is quite uniform below the first foot, with the maximum at about 5 feet below the surface. In deep clay areas, where irrigation has been moderate and well managed, the maximum salt content is from the third to the sixth foot. On some of the bench lands and on the alkali soils along the river the maximum amount of alkali is found in the first or second foot, with generally an accumulation on the surface due to evaporation of subsoil water, which is near enough to the surface to be raised by capillarity. In the irrigated soils along the canals the amount of alkali in the first 6 feet is usually less than 0.20, and generally increases downward. In one place where a heavy growth of greasewood was seen no injurious quantities of salts were found until the twelfth foot was reached. From there down to the sixteenth foot the soil was moist and carried considerable quantities of sulphates.

The source of the alkali found in the upper bench land and most of that in the level area south of it is the shales underlying the sandstones on the north side of the valley. The sandstone beds have also contributed a little, but by far the most of it came from the underlying shale. Exposures of this shale in the hills are usually covered with a deposit of salt, and many smaller beds and veins of salt—mostly calcium sulphate—were found in such places. The origin of the alkali in some of the river-deposited sandy loams is mostly in the seepage water coming from the bench lands.

The composition of the alkali in the bench soils is quite uniform, consisting principally of sulphates, with small amounts of bicarbonates, chlorides, and some traces of alkaline carbonates. In boring samples sulphates were found in both the amorphous and crystalline forms, these having separated after the deposition of the soil or having been transported as such with the soil.

A notable feature in the composition of the alkali in the Billings area is the remarkably small amount of hydrogen carbonates present. This accounts for the small quantity of normal carbonates or black alkali encountered. Moreover, there seems to be none in the shales from which the alkali originated. Probably the reason for such small quantities of bicarbonates is due to some extent to the large amounts of sodium sulphate present, which, according to work done in the Bureau laboratories, drives back the bicarbonates to the normal carbonates. The probable result in the soil would be the formation of lime carbonate.

It is of interest to compare some of the alkali conditions as they existed in 1898, the time of the first examination, and in 1902, the time when the soils of the area were studied. The following table gives data for such a comparison:

Table showing alkali conditions of the soil in 1898 and 1902.

DETERMINATIONS MADE IN 1898.

No. of boring.	Location.	First foot.	Second foot.	Third foot.	Fourth foot.	Fifth foot.	Sixth foot.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
65	¾ mile W. of NE corner sec. 1, T. 1 S., R. 25 E	0.57	0.49	0.34	....	(a)	(a)
66	¾ mile W. of NE. corner sec. 1, T. 1 S., R. 25 E.	.64	.38	.31	0.34	(a)	(a)
33	¼ mile W. of SE. corner sec. 2, T. 1 S., R. 25 E	.19	.24	.44	.46	0.46	0.31
34	S. center sec. 2. T. 1 S., R. 25 E	.70	.52	.41	.32	.32	.27
40	S. center sec. 5, T. 1 S., R. 26 E	.35	.89	.23	.17	.20	....
11	Center NE. ¼ sec. 4, T. 1 S., R. 26 E	.10	.51	.28	.17	....	....
12	⅛ mile NW. of center sec. 4, T. 1 S., R. 26 E	.32	.41	.41	.47	....	....

DETERMINATIONS MADE IN 1902.

		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
62	¾ mile W. of NE. corner sec. 1, T. 1 S., R. 25 E	2.20	1.24	0.66	0.58	....	0.66
67	¼ mile W. of SE. corner sec. 2, T. 1 S., R. 25 E.	.54	.41	.51	.60	0.52	.40
69	S. center sec. 2, T. 1 S., R. 25 E	3.00	....	.45	....	.37	....
12	S. center sec. 5, T. 1 S., R. 26 E	.93	.56	.40	.30	....	.36
29	Center NE. ¼ sec. 4, T. 1 S., R. 26 E	.60	....	.25	....	.42	....
30	⅛ mile NW. of center sec. 4, T. 1 S., R. 26 E	2.50	2.35	1.35	.98	1.20	....

[a] Not determined.

As the method of determination—by means of the electrolytic bridge—was the same in both instances, these borings can be compared quite safely. It will be seen that the conditions in places were much worse in 1902 than in 1898, as regards both salt on the surface and in the subsoil.

The following table shows the analyses of the standardization crusts and solution. Sulphates predominate, principally of sodium, the latter constituting from two-thirds to three-fourths of the total. Chlorides are not present in large quantities, and estimable carbonates occur in only two crusts.

Chemical analyses of crusts used in standardization.

Constituent.	6600. Near NW. corner sec. 2, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6601. Center sec. 10, T. 1 S., R. 26 E., soil 0 to 10 inches.	6602. Center sec. 10, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6603. S. center sec. 9, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.	6604. Center sec. 8, T. 1 S., R. 26 E., crust 0 to 1 inch.	6605. W. center sec. 34, T. 1 S., R. 26 E., alkali crust 0 to 1 inch.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	0.79	2.99	0.16	3.63	4.14	1.85
Magnesium (Mg)	1.79	.85	.24	2.01	2.57	2.95
Sodium (Na)	28.16	20.56	31.73	23.51	22.06	25.03
Potassium (K)	.72	9.63	.88	2.78	2.79	1.08
Sulphuric acid (SO_4)	67.73	45.85	59.93	62.98	61.06	66.49
Chlorine (Cl)	.33	Trace.	1.48	3.24	4.70	1.54
Bicarbonic acid (HCO_3)	.48	16.06	2.83	1.85	2.68	1.06
Carbonic acid (CO_3)	Tr.	4.06	2.75	....	....	....
Conventional combinations:						
Calcium sulphate ($CaSO_4$)	2.71	10.07	.55	12.29	14.00	6.08
Magnesium sulphate ($MgSO_4$)	8.90	4.06	1.22	9.91	12.76	14.58
Sodium sulphate (Na_2SO_4)	85.57	35.12	85.06	66.66	55.68	72.93
Potassium sulphate (K_2SO_4)	1.60	21.41	1.96	6.18	6.15	2.41
Sodium bicarbonate ($NaHCO_3$)	.67	22.06	3.90	2.55	3.69	1.46
Sodium carbonate (Na_2CO_3)	Tr.	7.28	4.87	....	....	....
Sodium chloride (NaCl)	.55	Tr.	2.44	5.41	7.72	2.54
Per cent soluble	44.68	0.934	17.00	2.59	1.79	9.04

Chemical analysis of standardization solution.

Constituent.	Per cent.	Constituent.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	0.89	Calcium sulphate ($CaSO_4$)	3.03
Magnesium (Mg)	1.83	Magnesium sulphate ($MgSO_4$)	9.06
Sodium (Na)	26.24	Potassium sulphate (K_2SO_4)	8.14
Potassium (K)	3.65	Sodium chloride (NaCl)	2.91
Sulphuric acid (SO_4)	63.68	Sodium carbonate (Na_2CO_3)	1.45
Chlorine (Cl)	1.76	Sodium bicarbonate ($NaHCO_3$)	1.56
Bicarbonic acid (HCO_3)	1.13	Sodium sulphate (Na_2SO_4)	73.85
Carbonic acid (CO_3)	.82		

As much of the area, especially the clay soils, was originally charged with alkali, the blame for the present serious conditions can not be laid wholly to seepage resulting from irrigation of the higher lying lands. Seepage and drainage waters are, however, doing considerable damage, for, as a rule, the alkali areas where standing water is within 6 feet of the surface have an accumulation of salts.

The following table shows the areas of alkali lands in the survey around Billings:

Area of alkali lands, Billings, Mont.

Alkali.	Sq. miles.	Acres.	Per cent.
Less than 0.20 per cent	67.1	42,944	62.7
From 0.20 to 0.40 per cent	13.5	8,640	12.6
From 0.40 to 0.60 per cent	15.6	9,984	14.6
From 0.60 to 1 per cent	8.7	5,568	8.1
From 1 to 3 per cent	2.1	1,344	2.1
Total	107.0	68,480	....

The first step in the reclamation of these lands is to lower the subsoil water. The question resolves itself into one of underdrainage. Some small attempts at reclamation have been made by digging shallow ditches, but these soon filled, and little benefit was derived from their use. The subject of reclamation of lands in this area will be referred to in the chapter on the reclamation of alkali lands.

WALLA WALLA AREA, WASHINGTON.

This area occupies the south-central part of Walla Walla County and was surveyed in 1902 by J. Garnett Holmes. The climate of the country is semiarid, the annual rainfall being 17.7 inches. The climate is excellent for the growth of cereals, fruits, and vegetables. The surface of the country is rolling, with no level areas except along the small streams. Irrigation is only practiced in these small valleys, as the hills are too rough to make possible any method of applying water. The soils consist mostly of sandy loams and light silty loams that have been derived from lacustrine deposits mixed with considerable quantities of volcanic ash.

Toward the western part of the area, along the Walla Walla River and Mud and Dry creeks, the land contains alkali, some of it so much as to be practically abandoned. Even in the small valleys about Walla Walla and in some places on hillsides patches of alkali are seen, but such patches are small in extent, and the percentage of alkali present in the soil is very low.

All of the soil of the valley has traces of alkali. Those areas where the quantity is harmful are due to the localizing and concentration of the alkali by the water, which takes up a small quantity of salt and deposits it at the point of evaporation. Thus an accumulation of alkali is the usual accompaniment of a high water table. Small alkali patches at the base of hills are caused by the seepage from rain water, which soaks into the hills, dissolves the easily soluble salts, and then in part slowly seeps out and is evaporated, leaving the alkali on or near the surface.

The alkali is nearly all carbonate and bicarbonate of sodium. While the total salts in the surface 6 feet rarely exceed 0.20 per cent, there is quite an area in the western part of the district, along the Walla Walla River, where the surface 3 feet contains more than 0.20 per cent of black alkali alone.

Only a small part of the area surveyed contained enough alkali to be impaired for agricultural uses. Five one-hundredths per cent in the soil from which the plants feed is enough materially to injure sensitive crops like wheat and many of the vegetables. Barley will do fairly well on such land, and alfalfa, if once well established, will grow, though it will not thrive. Pears and apples are affected, but will live. As this quantity is increased, however, the list of plants that may be grown rapidly diminishes until, when the concentration reaches 0.10 per cent, none of the crops of the valley will grow. All lands containing more than 0.10 per cent must be reclaimed before crops can be grown.

There is no alkali land in the area that can not be economically reclaimed. It is all situated in the small valleys along streams and when under cultivation and free from alkali is the most valuable soil in the county. The soils are all of such an open and porous nature that alkali may readily be washed from them, and the numerous small streams that intersect the area are usually far enough below the level of the valley to afford good outlets for drains. These same streams afford ample and excellent water for irrigating all the land contained in the valleys. The present condition of the alkali areas is due either to neglect or to improper treatment in cultivation. The most efficient method for reclaiming the land is to remove the alkali in the way it was accumulated—that is, through the action of water. If the land was continuously cultivated, or a mulch maintained in some other way, the rainfall would in the course of a few years reclaim the areas that are now only partially damaged. But since water for irrigation can be obtained so readily and cheaply the rainfall should be augmented by irrigation.

LOWER ARKANSAS VALLEY, COLORADO.

This area, surveyed by Macy H. Lapham and party in 1902, lies in southeastern Colorado. It embraces large areas in Otero, Bent, and Prowers counties, and is traversed from west to east by the Arkansas River. This area is one of the most important agricultural sections of the State, and is watered by some of the most extensive storage-reservoir and canal systems of the arid West. Its soils are famed for their fertility, and the Arkansas Valley is known for its stock-feeding industries and for the production of alfalfa, sugar beets, melons, fruits, and vegetables. The area surveyed has an extent of 945 square miles.

The area receives an annual rainfall of about 13 inches. The surface features of the area consist of the Arkansas Valley proper and the uplands. The latter consist of a succession of smooth, even, gently undulating prairies characteristic of the Great Plains, broken in places by arroyos with vertical sides, and traversed by streams of a more or less intermittent flow. The Arkansas Valley proper forms a trough from 2 to 5 miles wide, and from 100 to 300 feet deep, carved out by the river. Prominent bluff lines mark its borders through much of the valley. At other points more gradual slopes prevail, with minor terraces of gravel, sand, heavy silt, and clay deposits. The soils naturally fall into two divisions—the valley soils consisting of a complex mass of sands, gravels, and clays deposited by the river, and the generally deep upland soils derived from the breaking down of sandstones, shales, and limestones. All waters taken from the Arkansas River and its tributaries show a considerable quantity of soluble mineral salts, but these are generally of the less harmful class. With proper cultivation and drainage no harmful results should follow their use.

The source of the artesian water of the Arkansas Valley is the Dakota sandstone. These rocks outcrop over large areas in the vicinity of the mountains, where the main supply is received. The character of the waters also varies considerably, all of them being mineralized to a greater or less extent, depending upon the quantity of the infiltrating waters from the cretaceous shales, which are heavily charged with the alkali salts. Analyses of these waters show the main salts to consist of sodium bicarbonate, sodium sulphate, and magnesium sulphate. The quality of the ground water as a whole is poor and it is often unfit for domestic use. The surface wells are often contaminated by organic matter and surface drainage, and the waters are usually too highly charged with alkali salts to be used for drinking purposes. Upon the uplands of the Arkansas Valley and above the canals the water table lies at relatively great depths. Near the canals, however, and through the valley bottoms it appears very near the surface. While the damage from the accumulation of alkali and seepage waters in the valley is much less than in many sections of the arid West, it is sufficiently serious to cause alarm. The greatest

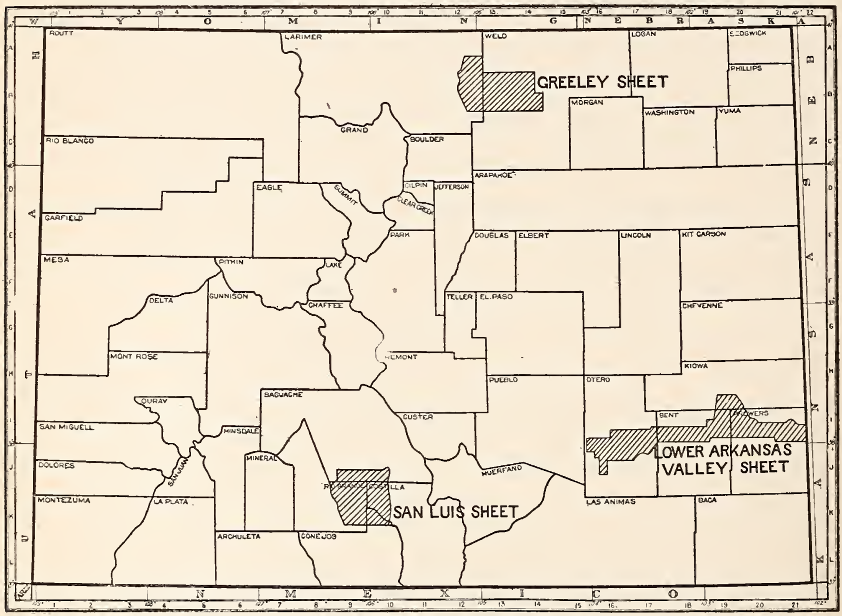

FIG. 9.—Sketch map showing location of areas in which alkali has been studied in Colorado.

injury has occurred in the bottoms of the main valley and of the many tributary valleys extending outward from it. In the western part of the area the local depression known as Patterson Hollow is one of the worst affected areas. Eastward from this point many parts of the bottoms show similarly bad conditions. Springs carrying a considerable quantity of alkali-laden seepage water are frequent, and many local sloughs and bogs have been formed since the advent of irrigation. In nearly all these localities the conditions seem to be rapidly growing worse and means should be taken at once to put a stop to the evil.

All of the seepage water contains large quantities of alkali salts, the sulphates and carbonates predominating. Black alkali has been detected, but exists only in small proportions. The salts in the seepage water are derived from the leaching of the cretaceous shale rocks and adjoining soils. Analysis of the cretaceous shale shows large quantities of sodium bicarbonate, calcium sulphate, calcium chloride, and magnesium chloride.

In nearly all cases it was found that wherever there is a concentration of 0.20 per cent or more of alkali in the first 6 feet of soil the water table was found 6 feet or less from the surface. This relation shows the effect of the seepage waters upon the distribution of the alkali salts in the soils and the accumulation of alkali upon the surface.

In the uplands the soils damaged by alkali occur as relatively narrow strips running parallel with the canals or as broader bodies occupying local draws, flats, or former seepage lake bottoms.

In the valley proper the damaged areas usually occur upon the heavier soils of the bottoms. In the southeastern part of the survey several alkali areas covering creek bottoms contain from 0.20 to 1 per cent of alkali in the first 6 feet, having the greater proportion of all the salts in the subsoil. The surface soil is free from alkali or nearly so. In this condition the lands, although heavily charged with alkali, will produce good crops until the alkali of the subsoil is brought to the surface by irrigation and seepage waters.

Sodium sulphate is the prevailing alkali salt of the area. This, with other common salts, is derived largely from the cretaceous shales. Sodium chloride is second in quantity and importance, while calcium sulphate, or gypsum, and magnesium sulphate form large proportions of the remaining alkali salts of the region. Sodium bicarbonate is generally found, often in considerable quantities, in the irrigation and seepage waters, but the injurious sodium carbonate does not exist in harmful quantities in either the soil or irrigation waters. This salt has been detected in solution in seepage waters of poorly drained areas, where it probably owes its formation to conversion from the bicarbonate through deficient drainage, which favors this chemical reaction.

Under normal conditions the alkali salts of the valley occur only in the subsoil, the rainfall being sufficient to leach them from the immediate surface. With irrigation the subsoil becomes filled with water and the water table of the lower lying lands is raised. As the irrigation and seepage waters percolate through the soil, the readily soluble salts are leached away and carried to the lower lands, and there, by the evaporation of these waters, the dissolved material is left upon the surface as an alkali crust.

Several methods for the reclamation of alkali lands have been tried in this area. Prominent among these are the removal of alkali crusts by scraping, washing away of the surface concentrations by heavy flooding, the cultivation of alkali-resistant crops, and the application of gypsum. All of these may under certain conditions be of value in aiding the removal of the alkali salts, but for the reclamation of lands containing any considerable quantities of alkali all are inefficient.

Several examples of tile drainage and its effects may be seen in this area at the present time. At the time the survey was made, in 1902, these systems had only been in use a few months, but the results were very gratifying, especially upon the lands of the American Beet Sugar Company at Rockyford. The system during the summer of 1902 resulted in lowering the water table from 1 to 2 feet.

YUMA AREA, ARIZONA-CALIFORNIA.

In the early part of 1902 a soil survey was made of the valley lands below Yuma, the soil and alkali maps and report being published in the Field Operations of the Bureau of Soils for that year. In the winter of 1903–4 a large party in charge of J. Garnett Holmes was sent to the district to survey and classify all the lands below the Laguna dam site on each side of the river. All of the alkali lands, or those having a high water table, are included in the bottom lands immediately along the Colorado River from Laguna dam site about 20 miles up the river from Yuma to the Mexican boundary line, about an equal distance down the river.

The climate of this region is distinctly arid, the annual rainfall being less than 3 inches. The soils of the valley are nearly all sandy, only small areas of heavy soils being found.

About 60 per cent of the bottom lands receives annually a heavy flooding from overflow waters of the Colorado. These overflow lands are thus washed clear of any salts that may have accumulated during the season and are uniformly free from heavy accumulations of alkali. Along the outer edge of the lands overflowed, however, and on isolated high knolls within the overflowed area, alkali has accumulated. Accumulations have also occurred in places at the foot of the mesa land which bounds the valley, due to seepage from the mesa lands above. All these accumulations may be attributed to the same cause—subirrigation or the lifting of the water to the surface, there to be evaporated and leave behind its small load of soluble salts. With the water table within capillary reach of the surface almost the entire year and greatly raised during the overflow season, at which time the temperature is very high and evaporation enormous, it is small wonder that these lands contain large amounts of alkali. The fine sandy loam soil, because of its great capillary power and slight resistance to the passage of water through it, is always the soil containing the greatest quantity of salts.

The diking and draining of the overflow lands, and the installation of sufficient drainage for the nonoverflow lands not yet irrigated, are problems for the experienced engineer and are being carefully considered by the engineers of the Reclamation Service. But what of the actual reclamation of alkali lands? This question has been answered by the experience of the settlers. When the lands below Yuma were settled and irrigation began, many acres were heavily charged with alkali. These lands were leveled and heavily flooded, until now some of the best alfalfa fields in our irrigated regions are found on these lands once heavily impregnated with alkali. The whole country is underlain by sand, which allows the percolation of ground water into which the salts are washed. There can be no question that the flooding in irrigation and care in cultivation will reclaim the lands already filled with alkali and prevent the other lands from becoming filled if there be sufficient drainage to prevent swamping.

The alkali here is of the white kind. Following is a table giving a number of analyses of alkali crusts and soils:

Chemical analyses of salts in alkali soils.

Constituents.	6501. SW. corner No. 2–40, sec. 25, T. 8 S., R. 24 W.; fine sandy loam, 0 to 72 inches.	6506. SE. corner No. 14–40, sec. 18, T. 9 S., R. 23 W.; sand, 0 to 48 inches.	6504. Near center sec. 2, T. 9 S., R. 24 W.; loam, 0 to 36 inches.	6503. Under No. 6502; clay loam, 36 to 72 inches.	6509. NW. corner No. 1–40, sec. 26, T. 8 S., R. 24 W.; sandy loam, 0 to 72 inches.	6502. Center S. side No. 15–40, sec. 36, T. 8 S., R. 23 W.; loam, 0 to 36 inches.	6511. E. side No. 9–40, sec. 12, T. 9 S., R. 24 W.; sandy loam, 0 to 72 inches.	6517. Center N. side, sec. 27, T. 8 S., R. 24 W.; alkali crust, 0 to 1 inch.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	9.42	5.18	2.72	1.74	9.02	5.27	3.87	2.04
Magnesium (Mg)	2.53	.99	1.27	1.43	4.45	2.49	2.07	1.96
Sodium (Na)	11.23	24.54	27.80	29.25	17.66	25.03	29.29	32.04
Potassium (K)	11.60	4.38	4.17	3.97	3.34	3.58	1.14	2.10
Sulphuric acid (SO_4)	28.26	32.96	18.51	13.68	18.26	14.64	14.07	4.66
Chlorine (Cl)	21.74	22.39	35.73	41.35	43.93	46.36	47.60	56.98
Bicarbonic acid (HCO_3)	15.22	9.56	9.80	8.58	3.34	2.63	1.96	.22
Conventional combinations:								
Calcium sulphate ($CaSo_4$)	32.25	15.34	9.07	5.88	25.83	17.86	13.09	6.61
Magnesium sulphate ($MgSO_4$)	6.88	4.78	6.17	6.99	.00	.00	6.00	.00
Potassium chloride (KCl)	22.10	8.36	7.98	7.63	6.34	6.81	2.18	4.00
Sodium chloride (NaCl)	13.77	30.09	52.71	62.18	41.98	59.17	72.68	81.15
Sodium bicarbonate ($NaHCO_3$)	21.02	13.14	13.36	11.76	4.56	3.58	2.67	.28
Sodium sulphate (Na_2SO_4)	.00	28.29	10.71	5.56	.00	2.85	.00	.00
Calcium chloride ($CaCl_2$)	.00	.00	.00	.00	3.89	.00	.00	.25
Magnesium chloride ($MgCl_2$)	3.98	.00	.00	.00	17.40	9.73	3.88	7.71

Chemical analyses of salts in alkali soils—Continued.

Constituents.	6515. Center S. side sec. 20, T. 8 S., R. 23 W.; alkali crust and mulch, 0 to 1 inch.	6520. Center S. side No. 13–40, sec. 36, T. 8 S., R. 23 W.; alkali crust and mulch, 0 to 1 inch.	6516. NW. corner No. 1–40, sec. 26, T. 8 S., R. 24 W.; alkali crust, 0 to 1 inch.	6525. No. 6–40, sec. 9, T. 10 S., R. 24 W.; alkali crust, 0 to ½ inch.	6526. No. 14–40, sec. 6, T. 10 S., R. 24 W.; alkali crust, 0 to ½ inch.	6522. N. side sec. 33; alkali crust, 0 to 1 inch.	6519. No. 12–40, sec. 36, T. 8 S., R. 24 W.; alkali crust, 0 to ½ inch.	6523. Center of sec. 17, T, 9 S., R. 23 W.; alkali crust, 0 to 1 inch.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	6.56	8.78	5.70	2.35	0.92	1.55	0.87	1.55
Magnesium (Mg)	2.67	3.39	6.76	.45	.28	1.00	.04	.25
Sodium (Na)	26.83	20.81	20.99	28.50	32.70	27.65	37.46	31.49
Potassium (K)	1.22	4.87	2.14	4.24	1.77	4.63	.88	6.50
Sulphuric acid (SO_4)	2.31	1.76	.87	41.82	37.73	20.75	10.64	5.31
Chlorine (Cl)	59.73	59.88	63.09	21.80	26.40	43.94	49.86	53.66
Bicarbonic acid (HCO_3)	.68	.51	.45	.64	.20	.48	.25	1.24
Conventional combinations:								
Calcium sulphate ($CaSO_4$)	3.25	2.50	1.23	7.98	3.14	5.26	2.97	5.28
Magnesium sulphate ($MgSO_4$)	.00	.00	.00	2.23	1.40	4.98	.36	1.27
Potassium chloride (KCl)	2.33	9.28	4.08	8.08	3.39	8.82	1.69	12.39
Sodium chloride (NaCl)	67.50	52.33	52.87	29.65	40.90	60.96	80.72	78.53
Sodium bicarbonate ($NaHCO_3$)	.93	.70	.61	1.15	.27	.66	.34	1.71
Sodium sulphate (Na_2SO_4)	.00	.00	.00	50.91	50.91	19.32	13.92	.82
Calcium chloride ($CaCl_2$)	15.48	21.90	14.70	.00	.00	.00	.00	.00
Magnesium chloride ($MgCl_2$)	10.51	13.29	26.51	.00	.00	.00	.00	.00

The water for irrigation all comes from the Colorado. Analyses of this water show no harmful amount of salts. No damage should be experienced from its use if applied in flood irrigation, or in the case of furrow irrigation on alkali-free lands, if occasional surface smoothings and floodings are given to wash out of the surface the accumulations of salts that must result from this method of applying water. The rainfall in this region is too slight to perform this office, so floodings will be necessary.

BLACKFOOT AREA, IDAHO.

The Blackfoot area was surveyed by W. E. McLendon in 1903. It includes all of the irrigable lands of the Snake River Valley for a distance of 50 miles in Brigham and Fremont counties. The area contains approximately 428 square miles. The annual rainfall amounts to about 9 inches.

The area is practically free from injurious accumulations of soluble salts in the soil. With only two exceptions no alkali was encountered. In these places the water table had risen near the surface and caused the accumulations which occurred at or near the surface. In places the water table was found to be rising, and unless proper precautions are taken more trouble from alkali and seepage waters will be experienced in the future.

SOLOMONSVILLE AREA, ARIZONA.

The Solomonsville area was surveyed in 1903 by Macy H. Lapham and N. P. Neill. The area comprises about 108 square miles and is situated in the southeastern part of the Territory, lying along the valley of the upper Gila River. The climate is essentially arid, the average annual rainfall being less than 10 inches. The Gila Valley is almost wholly inclosed by rugged mountain ranges consisting of granite, with intrusions of volcanic rocks, usually of recent date. The river bottom or valley trough occupies a tract from 1 to 5 miles in width, through which flows the Gila River. From the valley trough the bottom extends outward with a gentle slope to the bluff lines, marking the margins of the mesa lands.

The soils of the area naturally fall into two widely separated divisions, viz, colluvial soils and alluvial soils. The colluvial soils make up the original foot slopes of the mountains and consist of mountain waste deposited in gently sloping plains by intermittent floods from cloud-bursts falling upon the mountain sides. These soils consist of sands, sandy loams, and gravelly loams. The alluvial soils include those formed by river sediments brought long distances in suspension and deposited by floods along the river flood plain. These soils include fine sandy loams, silt loams, and deposits of coarse gravel.

Water was encountered in a few places along the lower valley at a depth of less than 10 feet, but the average depth of wells at the time of the survey was from 20 to 30 feet. In general the well waters of the Gila Valley carry large quantities of soluble salts, many of them being unfit for domestic use. Analyses of well waters showed the presence of considerable quantities of sodium chloride, sodium bicarbonate, and sodium sulphate.

Seepage water was abundant, but had collected to a dangerous extent in only a few localities. This water is accumulated by leakage of canals and laterals or by excessive irrigation of higher lying lands. Water in excess of the quantity required by growing crops percolates downward, fills the subsoil, and finds its way through the more porous substrata to lower levels and local drainage basins. In this way large areas of valuable land at lower levels are damaged, being converted into bogs, marshes, or alkali flats. The effect of this upon the composition and distribution of the alkali salts of the soil is important. Not only does a water-logged soil lead to the formation of alkali salts and their concentration within the zone of root activity, but the excess of water retards aeration and produces harmful changes in the physical structure of the soil. Small bodies of land damaged by seepage water were found along the lower valley level throughout the area. In some cases such areas amount to hundreds of acres.

The alkali of the Gila Valley was found to be confined for the most part to the Maricopa silt loam, a compact and impervious soil formed by material deposited by the Gila River and its tributaries. There were about half a dozen places ranging from one-half mile to 3 square miles in extent where alkali prevailed in dangerous quantities. The proportion of alkali soil as compared with the size of the area surveyed was considerable. Over much of the area containing from 0.20 to 0.40 per cent most of the alkali was in the lower part of the 6-foot section. Alfalfa when once started makes nearly a normal growth, and in some cases does well. In soils where the salt content does not exceed 0.40 per cent, sorghum, sugar beets, and alfalfa may be grown with profit, provided precautions are taken in starting the crop, such as heavy irrigations before planting to start a downward movement of the salts into the subsoil. By the time they return to the surface the crop may have sufficient stand and vitality to endure the injurious effects of the salts.

Sodium chloride was of common occurrence and formed a large proportion of the alkali salts, both in the soils and underground waters. Sodium sulphate also occurred in large quantities, and with sodium chloride formed practically all of the white alkali of the area. Sodium bicarbonate and carbonate also appeared to some extent in the Gila Valley. Sodium carbonate occurred in large and dangerous quantities only in a few small spots. In the Gila Valley area the subsoils of the heavier type carry in the aggregate great quantities of alkali salts. Fortunately, however, irrigation is less frequent than in many western districts. The water table lies at such depth under a great part of the area that the movement of the salts upward takes place only to a limited extent. The accumulation of the alkali salts upon the surface results for the most part from evaporation of irrigating waters carrrying in solution the salts derived from percolation of the upper portion of the soil section. The water table plays but little or no part in the accumulation.

LARAMIE AREA, WYOMING.

The Laramie area was surveyed by N. P. Neill and party in 1903. The area lies in the south-central part of Albany County, extending in a southeast and northwest direction along the Laramie River for a distance of about 40 miles. The area is about 8 miles wide and includes approximately 309 square miles. The climate is essentially arid, the annual rainfall at Laramie being about 10 inches. The greater part of the area lies in the Laramie Plains. Since the formation of these plains the river has cut down through them, forming the Laramie Valley proper. The river flows through low banks that slope gradually back to the hills or level uplands, but at a few places there are precipitous bluffs. The uplands are more or less rolling, with an elevation of from 7,300 to 7,500 feet above sea level.

The soils may be divided into three general classes, according to their origin or manner of formation. These are, first, residual soils derived in place from the weathering of rocks; second, alluvial soils formed from the materials deposited by the river; third, colluvial soils formed from material carried from the mountains by transporting agencies.

Sandy loam soils prevail, with smaller bodies of gravelly loams and heavy clay soils. Water for irrigation is taken from the Laramie River and from chemical analyses appears to be of excellent quality.

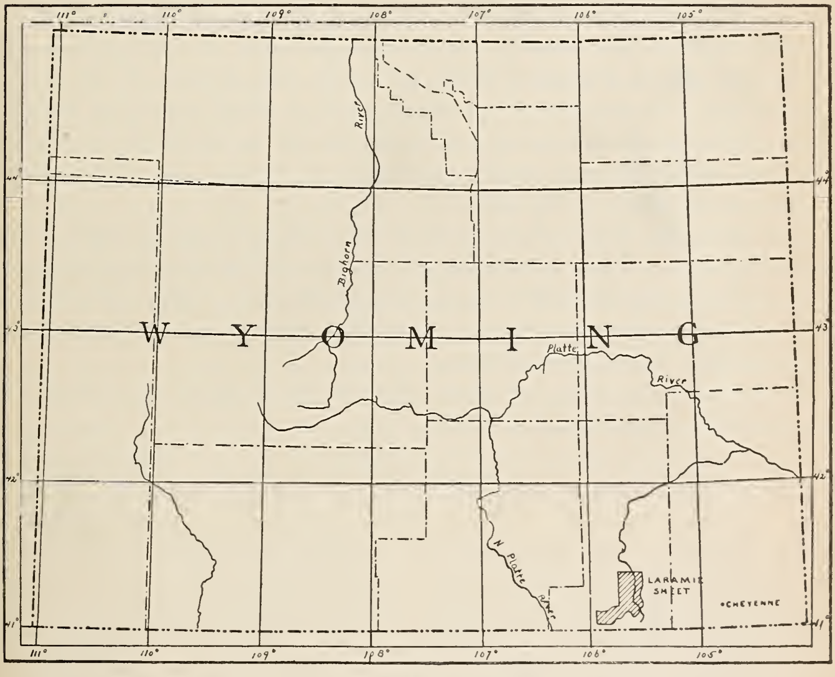

FIG. 10.—Sketch map showing location of areas in which alkali has been studied in Wyoming.

A considerable part of the once productive lands of the Laramie area has been injured by seepage waters. Drainage of these lands would not be difficult, as the fall toward the river is generally sufficient. Analyses of well water and water from the soda lakes show large quantities of sodium and magnesium sulphate, with varying amounts of chlorides. Carbonates occur, but generally in very small amounts.

Most of the alkali found in the Laramie area occurred in the lowlands along the Laramie River. The original source of the alkali is the exposed banks of clay, shale, and sandstone found in and around the area. Surface accumulations may be seen where these clays, shales, and sandstones outcrop. The alkali contained in these deposits is continually leaching out and being stored in the soil already containing a large percentage of soluble salts. Where such land is irrigated or washed by rain waters the alkali is dissolved and carried in the drainage water to the lower lying soils of the valley, in turn rendering them unfit for cultivation. Most of the alkali areas in the soils of the lower parts of the valley have been formed in this way.

The alkali found in the basins or lake bottoms came from the hills surrounding them. It has been washed into them by seepage waters until the amount they contain is very large. Springs are also the source of alkali, this being especially true of the soda lakes. The amount of alkali furnished by the springs, however, is slight compared with that which originates from the soils and certain of the rock formations. On account of the great store of alkali contained in the clays, shales, and sandstones much care should be exercised in irrigation and more attention paid to drainage to remove the salts as fast as they accumulate in the soils.

The character of the alkali found in the soils is much the same over the entire area. From a number of field determinations bicarbonates and sulphates were found to be the principal salts. Only very slight traces of carbonates were found. Chlorides occur in varying amounts, but generally in small quantities.

In the following table are shown the results of chemical analysis of an alkali crust from lake bottom:

Constituents.	Per cent.	Constituents.	Per cent.
Ions:		Conventional combinations:	
Calcium (Ca)	1.05	Calcium sulphate ($CaSO_4$)	3.56
Magnesium (Mg)	.88	Magnesium sulphate ($MgSO_4$)	4.37
Sodium (Na)	29.84	Sodium sulphate (Na_2SO_4)	88.95
Potassium (K)	.27	Potassium chloride (KCl)	.52
Sulphuric acid (SO_4)	66.14	Sodium bicarbonate ($NaHCO_3$)	.09
Chlorine (Cl)	1.76	Sodium chloride (NaCl)	2.51
Bicarbonic acid (HCO_3)	.06		
		Per cent soluble	91.46

On lands containing from 0.20 to 0.40 per cent of soluble salts in the first 6 feet of soil mature plants grow without injury, but it is difficult to get the less resistant plants started. Alfalfa can be grown on such soils, but when the upper limit (0.40 per cent) is reached the effect of the alkali is noticed in diminished yields. Sugar beets and barley, being to some degree resistant, will do well on such soils, but beans will not thrive, as the young seedlings are too tender. On soils which contain from 0.40 to 0.60 per cent of alkali only the most resistant plants will grow. If alfalfa is once established, it will continue to grow, but the yield will be light. Sugar beets and barley will do fairly well. Such soils are especially adapted to salt grasses, greasewood, and various alkali plants.

On soils containing from 0.60 to 1 per cent of alkali, the limit is about reached for cultivated crops. Where the soluble salt content of the soil is as high as from 1 to 3 per cent, it is practically impossible to grow any of the cultivated crops, and many of the salt grasses will not grow. Few weeds do well on such soils, greasewood and saltbushes comprising the principal vegetation. Lands containing over 3 per cent of alkali are practically bare of vegetation.

In the areas of gypsum the quantity of alkali varied from 0.20 to 3 per cent. The soil covering the gypsum is a loam, and the greatest amount of soluble salts occurred in the first 2 feet. The heavy clay soils contained on the average more alkali than any of the other soils of the area.

Much of the damage from alkali in the Laramie area must be ascribed to the excessive use of irrigation water. Fields that at one time were very productive have become practically worthless from the rise of alkali salts, and the water table has been raised to within a few feet of the surface in many places. Besides the rise of alkali, due to over-irrigation, considerable damage results from seepage from the canals. If catch canals were constructed along the main canal, where seepage is the worst, and if good drains were put in to carry away the surplus water used in irrigation, the rise of alkali in the soils would be checked, and in time the land could be reclaimed. The fall toward the river in most cases is ample, and on account of the loose texture of most of the soils drains would not have to be placed close together. In the lower lying areas, especially the old lake bottoms and basins, where there is no outlet, the problem of reclamation is more difficult. These places will probably remain alkali lakes, with the alkali continually increasing. Fortunately, however, these basins are only local, and are of relatively little importance.

SAN LUIS VALLEY AREA, COLORADO.

A soil survey of a part of the San Luis Valley in the southern part of Colorado was made by J. Garnett Holmes in 1903. This valley is situated in the south-central part of the State, and that section of the valley investigated has an average elevation of about 8,000 feet. As the rainfall is insufficient to produce paying crops, irrigation is practiced wherever crops are grown. Nearly the whole valley has artesian water at comparatively shallow depths, but this supply is used principally for watering stock. Water for irrigation comes mainly from the Rio Grande or the many small streams that issue from the mountains. The elevation and consequent short season limit the range of crops that may be grown, the principal ones being grain, peas, potatoes, and native grasses for pasture and hay.

The soils are nearly all very sandy, and generally have a high percentage of gravel, all being very leachy.

For all crops except the grasses for hay and pasture and limited areas of alfalfa, moisture is supplied by subirrigation. Water is run constantly during the growing season in small ditches from 150 to 300 feet apart in the fields, and the whole field subirrigated. This method is very wasteful of water, and has resulted in large districts becoming impregnated with alkali.

The reclamation of these alkali lands and the prevention of the spread of the evil has been discussed in the report upon this area, as follows:

> While not all of the alkali land of the valley will need to be drained, yet all the lands that need drainage, except those immediately along the streams, are alkaline, and some drainage is necessary in any comprehensive scheme of reclamation. Since, as has been several times stated, the accumulation of alkali is caused by the water coming from below or from subirrigation, the obvious thing to do to benefit the lands is to reverse the process and apply the water at the surface and let the current be downward. In order to make this possible, drains will have to be constructed on the wettest lands, and all the affected lands will need to be prepared so that in times of abundant water supply they will be liberally flooded.
>
> The soils of the valley are sandy, and their capillary power is very slight, so that with care in cultivation a very high water table may exist and yet but slight damage result from the rise of alkali. The principal crops of the country are shallow-rooted annuals, which are not injured by water comparatively close to the surface.
>
> In view of the fact that the alkali is wholly a surface accumulation, that the soil is sandy, coarse, open, and porous, and of very low capillary power, and that the crops are such as do not suffer from a high water table, it may be readily seen that any system of drainage either for alkali reclamation or for purely drainage purposes may be confined to a very limited part of the surface soil.
>
> The first step in this reclamation is to abandon the old method of exclusive subirrigation and prepare all affected lands for flooding. This will necessitate an initial expenditure of some money and labor, as small ridges and mounds must be leveled. Two dollars an acre, on an average, should be sufficient to cover this. Then, through the worst areas of alkali, and in the lowest parts, small drains should be constructed 2 or 2½ feet deep with an outlet into a main drainage ditch. This ditching should be done only after careful surveys and tests for alkali have been made, so that no unnecessary work be done and that the water table be not lowered sufficiently to make the lands too dry. Two dollars an acre, on an average, ought to pay for this ditching, which, together with the expense of leveling, would make a total outlay of $4 an acre for the affected lands. As soon as the lands are leveled and ditched, they should be heavily flooded to wash the alkali down, the salty water being carried away by the ditches. If one heavy flooding can be done in the spring before crops are sown, and then the crops flooded from time to time throughout the growing season, a crop can be grown the first year on almost any of the land that once grew crops. On the heavier soils, locally known as adobe, but represented on the map as San Luis sandy loam, the ditches would have to be closer together and deeper than on the sandy soils. This loam soil is usually much more alkaline than the sandy soils. On this heavier soil reclamation will be slower and more expensive, but when once reclaimed the land will be of lasting productiveness and very valuable.
>
> In reclaiming alkali land much loss can be avoided by planting only such crops as will withstand the quantity of alkali in the soil at the time of seeding. Land that will produce a paying crop of barley may be so alkaline as to be worthless for wheat and peas. A safe plan is to try first to grow only the most alkali-resistant crop suited to the climate. In the San Luis Valley this crop is barley, which, with the flooding, ought to produce fair crops the first year on any of the lands mapped as having less than 0.60 per cent of alkali. If the flooding be heavy and the crop shows little damage from alkali, it could be safely followed by a crop of peas. The peas should be grown as soon as possible in the reclamation,

as they greatly enrich the land and benefit the crop to follow. After a crop of peas is once grown, the ditches may be banked up in dry seasons and crops grown by subirrigation, if care be taken to flood the land every few years or when there is an abundance of water in the river.

The records show that at least once in four or five years there is sufficient snowfall to make a great surplus of water in the river. When once the lands can be made to produce crops, a copious flooding in these times of high water should keep the lands sufficiently sweet to grow crops in the intervening years by means of subirrigation. Lands immediately surrounding the abandoned areas have grown good crops for a number of years wholly from seepage from the higher lands, but they are beginning to show alkali on the surface and should be flooded. These wet lands surrounding the alkali areas are at present considered the most valuable in the valley, because they are not directly dependent upon the seasonal precipitation for their supply of moisture. As soon as the alkali lands are reclaimed they will rank with these lands in value, for a drought need never be experienced. The higher country to the westward acts as a water-storage region for these very lands, regulating the supply and always furnishing sufficient water for subirrigation in dry seasons.

After the lands are sufficiently reclaimed to grow the crops suited to this region, the greatest care should be exercised to prevent evaporation from the surface of the soil. Careful cultivation to preserve a mulch at all times when not actually growing a crop will do much to lengthen the time between floodings.

If the above recommendations are carried out, there can be no doubt that many lands now abandoned may be brought back into a high state of fertility.

Appended is a table of analyses of samples of alkali soils of the valley. The alkali is very spotted, some districts having quite a little of the carbonate. Rational methods of irrigation, however, should result in the reclamation of any of these lands, if undertaken and pursued with continuity of purpose.

Chemical analyses of salts in alkali soils.

Constituent.	No. 1.—1½ miles west of Montevista; crust, 0 to ½ inch.	No. 2.—Center east side sec. 18, T. 39 N., R. 8 E.; crust, 0 to ½ inch.	No. 3.—East side SE. ¼, sec. 29, T. 40 N., R. 8 E.; crust, 0 to ½ inch.	No. 4.—No. 4–40, sec. 6, T. 39 N., R. 7 E.; crust, 0 to ½ inch.	No. 5.—NE. ¼ sec. 24, T. 41 N., R. 7 E.; crust, 0 to 1 inch.	No. 6.—NE. ¼ sec. 29, T. 41 N., R. 8 E.; crust, 0 to 1 inch.	No. 7.—No. 13–40, sec. 33, T. 41 N., R. 8 E.; crust, 0 to 1 inch.	No. 8.—7 miles southwest of Alamosa; crust, 0 to ½ inch.	No. 9.—½ mile south of Alamosa; crust, 0 to ½ inch.
Ions:	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Calcium (Ca)	2.48	6.98	6.32	8.94	5.80	6.87	8.52	1.43	0.83
Magnesium (Mg)	.14	.96	.75	2.43	1.27	1.10	1.02	.08	.15
Sodium (Na)	28.49	22.90	21.92	11.00	23.05	23.82	17.61	30.06	33.05
Potassium (K)	1.59	.24	5.38	9.75	3.39	.18	7.27	1.07	2.06
Sulphuric acid (SO_4)	63.76	67.11	47.99	55.68	40.60	46.79	44.33	66.30	37.27
Chlorine (Cl)	2.33	....	15.39	....	17.40	12.91	16.03	.97	2.08
Carbonic acid (CO_3)	....	....	....	....	....	....	....	....	17.38
Bicarbonic acid (HCO_3)	1.21	1.81	2.25	12.20	8.49	8.33	5.22	.09	7.18
Conventional combinations:									
Calcium sulphate ($CaSO_4$)	8.42	23.73	21.46	30.28	19.66	23.35	28.97	4.86	2.98
Magnesium sulphate ($MgSO_4$)	.71	4.70	3.69	11.99	6.22	5.40	5.00	.40	.77
Potassium chloride (KCl)	3.04	....	10.26	....	6.50	.36	14.09	2.04	3.54
Sodium chloride (NaCl)	1.46	....	17.23	....	23.48	20.98	15.57	....	.99
Sodium bicarbonate ($NaHCO_3$)	1.65	2.53	3.06	17.07	11.88	11.45	7.15	.13	9.90
Sodium carbonate (Na_2CO_3)	....	....	....	....	....	....	....	....	30.73
Sodium sulphate (Na_2SO_4)	84.72	68.44	44.30	18.91	32.26	38.46	29.22	92.57	51.18
Potassium sulphate (K_2SO_4)	....	.60	....	21.75	....	....	....	....	....
Per cent soluble	15.07	1.66	3.20	.98	1.21	2.18	1.76	31.72	10.10

PROVO AREA, UTAH.

The Provo area was surveyed in 1903 by A. M. Sanchez. It includes an area of 370 square miles, and constitutes nearly all of the cultivated land of Utah County. The climate of the valley is characterized by a low annual precipitation, the total amounting to about 15 inches.

The area comprises two distinct topographic divisions. The first is an area of sloping land adjacent to the base of the mountains, and usually above the present systems of irrigation. This consists chiefly of coarse material, sand, gravel, stones, and bowlders, derived principally from wash from the mountains. The surface is usually rough and uneven. On account of insufficient water supply, a large part is not under cultivation. The second topographic region is larger and more level and is generally cultivated. It is composed of the finer sediments of ancient Lake Bonneville, subsequently modified by inflowing streams and weathering. The soils consist of clays, loams, and sandy and gravelly loams, with loams and gravelly loams as the prevailing types. The principal streams used for irrigation in the valley originate in the Wasatch Mountains. The water is of good quality, though generally the amount is insufficient for irrigating all the cultivated lands.

The level at which standing water is found is very changeable, depending on the character of the season. The principal cause of the high water table in much of the lands is seepage from irrigation on the higher lands. The wet lands to the east and southeast of Provo City and to the north of Spanish Fork, as well as in many other places, have been caused by seepage from the irrigation canals in the coarse and porous soils of the bench lands. It is obvious that great care should be exercised in the construction and use of canals, especially those on porous soils, and the unavoidable waste from the canals should not be allowed to accumulate in low places. Much of the wet land also is caused by springs and flowing wells, which are more or less numerous throughout the bottom lands. These wells keep the land in the vicinity saturated with water, making it swampy and unfit for cultivation, and while the water is usually free from injurious amounts of soluble salts, yet by continuous evaporation considerable alkali accumulates on the surface of the soil in these localities. A few ditches to conduct the water away from these wells to other parts of the fields, instead of allowing it to soak into the adjacent land, would prove very beneficial to lands already affected, and would prevent the further spread of alkali. There are at present over 2,000 acres of this wet land in the vicinity of Utah Lake, used chiefly for pasture and practically worthless, which, if properly drained, would have a greatly enhanced value.

On a small scale a certain amount of drainage is being done around Provo City, and in all of these cases fair success has been attained.

As a general rule, the alkali areas were found in lands of the lower levels, though in a few cases slight accumulations of salts were found in some of the bench lands. In the bottom lands the soil is usually heavier and poorly drained, and these conditions, together with the low position of the lands, favor the accumulation of soluble salts in the soil. For 2 or 3 miles from Utah Lake, and all along the side, more or less alkali land was found.

The principal source of the alkali in most of the area is in the evaporation of Utah Lake and seepage waters. While it is quite possible that some of the salts may be the result of the evaporation of the waters of former Lake Bonneville, which once covered this country, it is not probable that much of the salts found in the soil is directly derived from that source. Over most of the alkali areas found in the valley the surface of the soil is within capillary reach of the ground water, and consequently rapid evaporation at the surface is continually going on, with the result that salts are concentrated at this point. As a general rule, the greater part of the alkali found in the soils of this valley is in the first 3 feet of soil, little or no alkali being found below this depth. In some places of heavy soils underlain by clay the alkali is quite uniformly distributed throughout the first 6 feet of soil.

It was repeatedly noticed that the amount of alkali that sugar beets will stand is in great measure dependent on the character of the soil. In all cases it was found that where the soil was a loam or of heavier texture than a loam the amount of alkali required to injure crops was higher than where the soil was lighter in texture. Several cases were observed where sugar beets in a sandy soil were suffering with 0.65 per cent of alkali in the first foot of soil and 0.62 per cent and 0.55 per cent in the second and third foot, respectively, with the quantity of salt diminishing greatly in the lower depths. On the other hand, beets were found growing apparently well in a heavy loam soil with 1.40 per cent of alkali in the first foot, 1.50 per cent in the second, 1.55 per cent in the third, and an average of 1.50 per cent for the 6 feet. Similar observations on sorghum and alfalfa appear to confirm the above conclusions.

The following analyses of crusts give the chemical composition of the alkali in this area:

Chemical analyses of salts in alkali crusts.

Constituent.	NE. cor. sec. 19, T. 9 S., R. 1 E.	NE. cor. sec. 28, T. 9 S., R. 1 W.	SW. 4-40, sec. 10, T. 7 S., R. 2 E.	NE. cor. 6-40, sec. 3, T. 7 S., R. 2 E.
Ions:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Calcium (Ca)	2.96	0.34	1.48	0.52
Magnesium (Mg)	.97	.30	2.70	.72
Sodium (Na)	32.44	36.26	24.98	33.52
Potassium (K)	2.71	1.25	3.16	2.52
Sulphuric acid (SO_4)	1.18	3.55	45.91	12.22
Chlorine (Cl)	59.25	21.70	6.51	9.23
Bicarbonic acid (HCO_3)	.44	15.16	10.98	16.68
Carbonic acid (CO_3)	.05	21.44	4.28	24.59
Conventional combinations:				
Calcium sulphate ($CaSO_4$)	1.67	1.17	5.02	1.77
Calcium chloride ($CaCl_2$)	6.82	1.52	13.31	3.57
Potassium chloride (KCl)	5.14	2.37	6.05	4.82
Magnesium chloride ($MgCl_2$)	3.81	2.23	46.95	11.99
Sodium chloride (NaCl)	81.85	33.97	5.95	11.43
Sodium bicarbonate ($NaHCO_3$)	.61	20.88	15.18	22.95
Sodium carbonate (Na_2CO_3)	.10	37.86	7.54	43.47

In the Goshen Valley, with the exception of the bench lands immediately adjoining the mountains, and a few other small areas in the bottoms, sufficient salts occurred in all the soils materially to injure the crops or entirely to prevent profitable cultivation. Many large areas were found containing from 1 to 3 per cent of alkali. In this class of soils it is doubtful if any of the common agricultural crops will grow with any degree of success.

Black alkali (sodium carbonate) was found in more or less injurious quantities in some parts of the valley. It was seldom found, however, in amounts exceeding 0.10 per cent outside the Goshen Valley without the presence also of an excess of white alkali. In the Goshen Valley much of the land contained from 0.10 to 0.30 per cent of sodium carbonate. None of this land was then under cultivation, and it was evident from surface conditions that no agricultural crops would grow in the soil.

There is no doubt that the alkali soils of this valley, most of which are at present practically worthless, would, if freed from alkali and supplied with sufficient moisture, grow successfully any crop adapted to the region. There were at the time of the survey 49,408 acres of land in the valley containing more than 0.40 per cent of alkali to an average of 6 feet. Over most of this land soluble salts occurred in sufficient quantities either to be injurious to crops or entirely to prevent successful cultivation. The value of most of this land was nominal, varying from $5 to $15 an acre. If properly reclaimed, it would be worth, under irrigation, at least $80 an acre.

The following table shows the extent of the several grades of alkali land in the area:

Areas of alkali lands.

Grade.	Acres.	Per cent.
Less than 0.20 per cent	159,488	69.9
From 0.20 to 0.40 per cent	29,824	11.6
From 0.40 to 0.60 per cent	15,680	5.7
From 0.60 to 1 per cent	10,368	3.9
From 1 to 3 per cent	23,360	8.9
Total	238,720	....

BAKER CITY AREA, OREGON.

The Baker City area was surveyed in 1903 by Charles A. Jensen and W. W. Mackie. The area includes about 158 square miles situated in Baker County, in northeastern Oregon. The climate of the area is practically arid, as the rainfall is not properly distributed during the year to grow crops without irrigation. The annual rainfall at Baker City is about 14 inches. Baker Valley is about 3,300 feet above sea level, and is completely surrounded by mountains ranging from 1,000 to 6,000 feet above the valley level.

The soils consist of loams and gravelly and sandy loams. The soils are not deep, and everywhere in the valley proper they are underlain by coarse, well-rounded gravel. There is evidence that the soils in the central part of the valley have been brought there from the mountains by the streams and supplemented by washings from the foothills, while the soils along and just below the foothills are colluvial in origin.

The chief constituent of the alkali in the cultivated valley soils was found to be alkaline carbonate or black alkali. The subsoil water carries bicarbonates in solution, and when this water reaches the surface by capillarity it evaporates and leaves the salts behind. As evaporation proceeds the hydrogen carbonates, or bicarbonates, lose water and carbon dioxide, which changes the salts to the normal carbonate or black alkali. The subsoil also contains some alkaline carbonates, and the capillary attraction of these salts being much greater than that of any other constituent in the soil there is a strong tendency for these to concentrate at the surface. The surface deposit of alkaline carbonates is thus due partly to its formation from the hydrogen carbonates and partly to the salts being brought up directly from the subsoil.

In the southeastern part of the area, in one of the sandy loam types, the subsoil contained considerable alkali. The maximum salt content occurred in the third and fourth foot sections, and but very little, or less than 0.20 per cent, in the surface foot. The alkali here owed its origin to the decomposition of the rocks from which the soil has been derived, and was principally white alkali, although considerable alkaline carbonate was also found. These latter salts have also been formed in place. There is a great deal of lime in the subsoil of this type, and the calcium and magnesium carbonates have been dissolved to a certain extent, resulting in the formation of the hydrogen carbonates of their bases. These hydrogen carbonates then react with the soluble sodium and potassium salts, such as chlorides and sulphates, which are present in considerable quantities, forming the hydrogen carbonates of sodium and potassium. These upon reaching the surface change to the normal carbonates by the loss of carbon dioxide and water. Some alkaline carbonates are also formed in the subsoil, as these were found from 4 to 6 feet below the surface. The calcium and magnesium carbonates are soluble as such to some extent especially in the presence of other salts in solution. These carbonates then react directly with the sodium and potassium salts, forming soluble alkaline carbonates. But here, again, the strong capillary attraction of these salts causes them to be concentrated at or near the surface. In some cases as much black alkali was found in the second foot as in the surface foot.

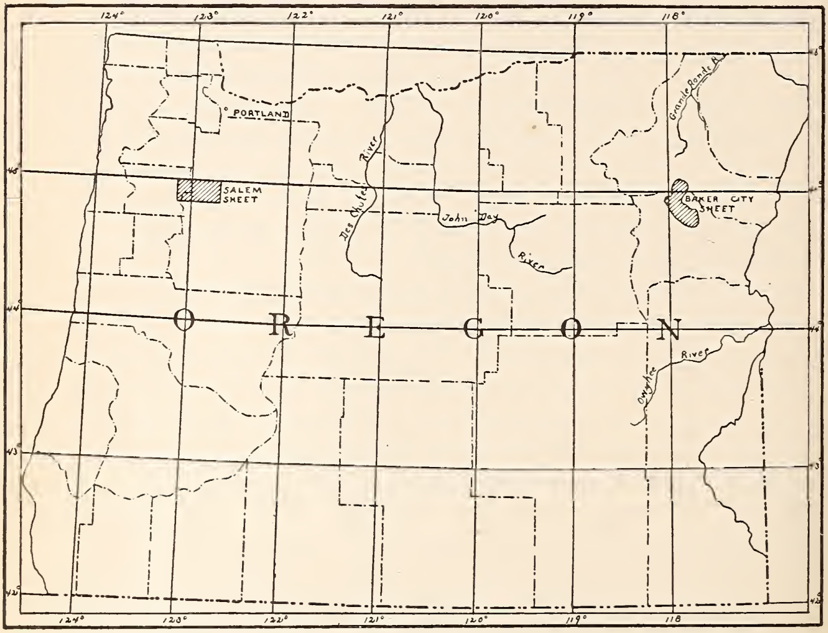

FIG. 11.—Sketch map showing location of areas in which alkali has been studied in Oregon.

In the areas of bad alkali surface conditions the alkaline carbonates were always present in excess of any other single component of the soluble salts, with the exception of hydrogen carbonates, and these are in reality potential alkaline carbonates. Sulphates were very often found, sometimes in large quantities, in the presence of the alkaline carbonates. Chlorides were nearly always present, but always in smaller quantities than the alkaline carbonates. The amount of hydrogen carbonates seldom exceeded that of the alkaline carbonates by more than two or three times.

Owing to the fact that in cultivated areas the maximum salt content occurs usually in the surface foot, the problem of alkali reclamation is not so serious as it would be if the subsoil contained excessive amounts of alkali. The character of the prevailing alkali—alkaline carbonates or black alkali—makes it necessary to prevent the surface accumulation of alkali as far as possible. The black alkali in the cultivated areas owes its origin to the evaporation of the subsoil water at the surface. Were the water table kept far enough below the surface to check this capillary process, it is evident that there would not be so much black alkali on the surface. The subsoil water should not be permitted to come nearer the surface than 6 feet. This can be accomplished by an economical use of water on the soils in which the underground water table is not yet too near the surface, and by underground drainage where the water table is already too high.

An attempt was made to obtain some information as to the resistance of different crops to alkaline carbonates. This is a difficult problem, because the conditions in the field are continually changing. The alkaline carbonates being readily soluble, every rain and every irrigation changes the concentration of the salts in the surface foot of soil. Again, when a long dry period occurs, and the temperature is high, evaporation is greatly increased, more subsoil water is brought to the surface, and the amount of the carbonates is considerably increased.

The following table exhibits the results obtained where the conditions appeared to have been comparatively constant, both in regard to crops and alkali content. The borings were made at the root crowns of the plants.

Tests for resistance of crops to alkaline carbonates.

Boring No.	Crop.	Condition of crop.	Alkaline carbonates.	Chlorides.	Sulphates.
			Per cent.	*Per cent.*	
54	Oats......	Poor; hardly worth cutting..........	0.065	None.	None.
78	.....do....	Good..................................	.03	0.055	Trace.
96	.....do....	Dead..................................	.05	.04	None.
97	.....do....	Dying after growing about 8 inches..	.04	.07	Heavy precipitate.
97	None.....	(Second foot of soil)..................	.03	None.	Light precipitate.
102	Oats......	Growing fairly well, but in chlorose condition.	.03	None.	None.
105	.....do....	Same condition as No. 102...........	.05	None.	Do.
186	.....do....	12 inches high, but not good crop....	.05	.225	
185	.....do....	2 to 3 feet high, well headed out......	.08	None.	Do.
138	Wheat....	Fairly good; will make average crop.	.035	None.	Do.
141	.....do....	Entirely bare ground; surrounding wheat 3 feet high.	.065	.16	Moderate precipitate.
142	.....do....	Good; 2 feet high and fully headed out.	.04	Trace.	None.
153	.....do....	Fair; plant 18 inches high, but not profitable crop.	.05	.16	Heavy trace.
136	Timothy..	Good; but only average crop; not heavy.	.07	None.	Not tested.
166	Barley....	Matured, but plants stunted, and poor stand.	.05	.025	Moderate precipitate.
182	Alfalfa ...	Chlorose, but growing fairly well; second crop.	.08	None.	None.
183	.....do....	Good; fair stand; second crop, 8 to 10 inches.	.08	None.	Do.
184	.....do....	Good; best that could be found in field.	.03	None.	Do.

It will be noticed that the presence of sulphates has considerable influence on the plants, since they apparently would not stand so much of the alkaline carbonates when the sulphates were absent. It is probable that some of the sulphate was magnesium, a salt which has as deleterious an effect on plants as the alkaline carbonates. It is very likely that in these tests the effect of the alkaline carbonates was modified by the presence of magnesium sulphates. The chlorides would undoubtedly have a somewhat similar effect, though to a less extent.

SAN JOSE AREA, CALIFORNIA.

The San Jose area was surveyed in 1903 by Macy H. Lapham. It occupies the northern part of the depression extending in a southeasterly direction from the southernmost extremity of San Francisco Bay and known as the Santa Clara Valley. This valley is one of the largest of the several coast valleys, and is of great economic importance to the State. The average annual rainfall in the valley is about 15 inches. Fogs are of frequent occurrence, usually appearing during the night and early morning of the summer months.

The soils are mainly of alluvial or colluvial origin, and are derived, by weathering and waste, from a complex variety of rocks of the surrounding mountains. In texture they grade from incoherent sands to extremely heavy and sticky adobes, usually occupying valley depressions, but sometimes extending over foothill slopes. With the exception of the axial valley trough and a few local depressions, these areas are well drained, and the accumulation of alkali salts has not taken place to so serious and extensive a degree as in the great interior valley.

Irrigation is usually practiced in the fruit districts, the supply being drawn mainly from an underground source by pumping. None of the waters used for irrigation purposes, whether drawn from wells or from streams, were found to contain injurious quantities of alkali. Of the underground supply, that drawn from the deeper wells is usually most pure. Owing to the cost of pumping and to a limited supply of irrigating waters which may be obtained from streams, there is a very general and commendable economy in the use of water for irrigation purposes, which is generally carried through iron pipes to the point of delivery, thereby entirely preventing loss by seepage. The advantages of frequent cultivation in preventing loss of soil moisture by evaporation are also generally recognized.

Alkali soils are not of general occurrence throughout this survey. They occur, however, in a few valley depressions and districts of arrested drainage, covering quite an extensive tract of heavy silty loams and adobe occupying a pronounced depression a short distance east of the city of San Jose, and extending in a northwesterly direction to the salt marshes of San Francisco Bay. Some of these soils are in this vicinity quite heavily impregnated with alkali salts, which an examination of waters from shallow wells indicates extend to considerable depths. In these salts the more destructive black alkali is lacking. Considerable portions of these areas have been already drained by tile and occasional open ditches. Owing to the limited supply and the high cost, no large amount of water is available for purposes of reclamation. The chief cause of these alkali-impregnated soils seems to have been the concentration of the salts by seepage from irrigation carried on upon adjoining higher fruit lands of porous structure. The condition of much of this land can be improved by an extension of the drainage systems. In the vicinity of the tidal marshes encircling the southern extremity of San Francisco Bay the soils are heavily impregnated with marine salts from saturation by sea water. A system of levees, drainage by pumping, and shallow cultivation might render a larger portion of this land available for grazing purposes, and in time perhaps capable of producing certain crops.

IMPERIAL AREA, CALIFORNIA.

In the winter of 1901 a soil survey was made of a part of the Salton Basin. Later, in the fall and winter of 1902–3, the survey was extended to include all of the region known as the Imperial country.

The whole Imperial country is a part of the Salton Basin, a former arm of the Gulf of California, which was cut off by the deposition of sediment from the Colorado River. Subsequent evaporation left dry the basin that is now being farmed. Rainfall is of such infrequent occurrence that no useful crops can be grown without irrigation, making a desert in the true sense of the word. The summers are intensely hot, the temperature often reaching 120° F. in the shade. The winter climate is not unpleasant, being characterized, however, by a great daily range in temperature. At night the thermometer often reaches 20° F., while the maximum is rarely less than 70° F.

All the soils of that part of the basin known as the Imperial country are made up of sediments brought in by the Colorado River. While some sand and sandy loam soils are found, the greater portion is made up of a heavy, sticky, compact loam and clay. These heavy soils are so compact that water penetrates them very slowly, and hence they are exceedingly difficult to cultivate or irrigate. Moreover, the whole valley, either in the surface or the subsoil, contains much alkali. That is, all the subsoil and much of the surface soil have alkali in harmful accumulations.

Generally considered, the drainage of this region within the soil itself is very poor. The channels of New and Salton rivers, and many deep gullies leading into them, furnish excellent regional drainage, with the lower part of Salton Basin as an emptying place.

At the time of the surveys the water table was from 20 to 40 feet below the surface and had in no wise been altered by irrigation.

Much of the land in the virgin state had such a percentage of alkali at the surface as to require sweetening by heavy flooding before profitable crops could be grown. Usually the amount of alkali increased with depth, if the surface had less than 1 per cent. The problems, then, that confronted the irrigators of the Imperial country, which are practically the same to-day, were: First, actually to reclaim from alkali much of the lands of the valley before any crops could be grown; second, to prevent the rise of alkali from the subsoil in a region where the subsoil is universally impregnated with salt and with a table of salty water 20 to 40 feet below the surface.

This matter is discussed at length in the report made upon the region in 1903, the following being a quotation from the same:

> In many regions, where lands originally good have become alkaline, the injury has resulted from the ignorance or carelessness of the agriculturists. A thorough knowledge of soil conditions at the beginning of cultivation, a careful, rational application of water in irrigation, and a system of cultivation and rotation of crops tending to benefit the land permanently would have been possible in most of these cases, and the harmful accumulations could have been wholly or partially prevented. But the danger has not been seen, or at least not admitted, until a part of the land has been so badly affected as to produce no crops. It is always easier to prevent the injury of lands than it is to reclaim them after they have become alkaline, and as long as partial crops can be grown, some returns can be had from the land itself for the money expended.
>
> The people of the Imperial country should recognize the fact that aside from the general problem of securing water for irrigation they have to solve perhaps the most serious agricultural problem of the arid West. Here is found a most refractory soil, much of it highly impregnated with alkali. The only way to benefit the land is to carry away the salts. The application of gypsum can not be of the slightest benefit. Little or no benefit will be derived from running water across the land with the expectation of flushing the alkali off the surface. The first water run onto the land may dissolve the surface salt and sink it into the soil a little way, but repeated tests made in this way have shown that the water as it comes off the lower end of the field contains no appreciably greater proportion of salt than when it was taken from the ditch above. The water must pass through the soil and find ready egress through natural or artificial drainage ways.
>
> The quantity of salt taken out of the soil by alkali-resistant crops, such as sorghum and sugar beets, is not appreciable, the benefit to the soil in such cases resulting mainly from the prevention of evaporation at the surface through cultivation and from the leaching of the salts into the subsoil by the irrigation water. If the subsoil be practically free from salt, as is often the case in arid regions, this vertical distribution of the salts alone is often all that is necessary so to reclaim the soil that sensitive crops can be grown. But it has been shown that in the Colorado desert the subsoil is the greatest source of danger, so that every bit of salt removed should be permanently removed. Whether this can be done depends wholly upon the drainage. The rapidity with which water leaches through and drains away from a soil is dependent upon the texture of the soil and subsoil. A loose, friable, sandy loam or sand takes and gives up water very readily, so that such a soil should be easily washed free from salts if there be an outlet for the drainage water. On the other hand, a sticky clay or loam takes water slowly, and drainage in such soils is poor. By far the greater extent of the soil of the valley is a sticky, plastic loam or clay, through which water passes very slowly. The natural drainage in the soil itself is very poor, and to be anything like adequate it must be supplemented by artificial drains to carry off the ground water as the salts are washed down from the surface. The channels of New and Salton

rivers furnish good natural outlets for these drains. If the heavier soils be drained and care be exercised in the handling of the lighter ones, little damage will be done to the latter. Tile drains are the best and in the end the most economical for draining the land. They are, however, expensive, and the question is, Will it pay?

Thoroughly to tile-drain the heavier soils will cost at least $25 an acre, and the work can be properly done only in a large way and through the cooperation of all the farmers in maintaining the main drains, etc. For the very worst alkali lands this will have to be done before any paying crops can be grown at all, and it is only a matter of time until it will have to be done on some of the other soils that will now produce fair crops. This cost, added to the cost for water stock, makes an initial expenditure of about $40 an acre.

That it will eventually pay to drain these lands there can be little doubt, but in the present state of the country concerted action will be difficult and individual effort futile.

Many of the present landowners have expended all their capital for first payment of water stock and for farm equipment, expecting to obtain sufficient revenue from crops to meet future payments and to improve their farms, and for these the expenditure of the sum necessary to reclaim the badly alkaline lands is out of the question. They can not wait for the lands to be reclaimed, and unless their first crops are a success they will be unable to meet their payments. Thus a scheme of reclamation that would be not only possible but profitable for a wealthy company or corporation is, under present conditions, well-nigh impossible for the individual landowner of the Imperial area.

The conditions can, however, be at least temporarily improved and the rise of alkali delayed by individual effort. The aim should be to loosen the heavier soils in every way possible, to assist the natural drainage, and to see that in irrigation all parts of the field are covered. Irrigation by surface flooding should be the only method of applying water on soils carrying at present a harmful quantity of salts, and for the lighter and freer soils a system of irrigation should be followed that will permit occasional flooding to wash below the surface accumulations that will be inevitable with furrow irrigation.

Moreover, on such soils as those of the Imperial area, in all cases where the harmful amounts of alkali lie in the subsoil and not in the surface, it should be possible so to irrigate using only enough water to grow grains or other shallow-rooted annual crops, that connection between the subsurface and the irrigation water will not be made, thus preventing the rise of alkali. Such careful irrigation can be continued indefinitely without injury to the land When the surface 2 feet or so of soil contain an excess of salt, however, or when the salts from below have risen through the improper application of water or the rise of the water table, then it is useless to attempt cultivation with the sparing use of water, but the opposite method of thoroughly drenching the land, which has first been provided with adequate subdrainage, is the only safe and efficient one to follow. The one idea in this method is actually to wash and sweeten the land, dissolving the salts in the irrigation water, and carrying them away in the water passing off through the drains. The quantity of salts that can be removed in this way when the soil allows a ready percolation of water, the flooding is heavy, and the drainage system adequate, is astonishing. Means, in Bulletin 21 of this Bureau, points out that in Egypt lands of the heaviest character, containing 8 or 9 per cent of salt to a depth of several feet, with surface accumulations often as high as 40 or 50 per cent salt, are commonly reclaimed sufficiently to grow resistant crops in one year, cotton in two or three years, or corn in four years. In order to accomplish this, the drainage water must remove hundreds of tons of salt for every acre reclaimed.

Of the 693,696 acres surveyed, 296,256 acres of the level part contain less than 0.40 per cent of alkali. All of this part may be cultivated indefinitely to all the crops suited to the soil and climate, provided care is taken in irrigation and cultivation to prevent a rise of the salts from below. Of the remainder, 91,008 acres contain from 0.40 to 0.60 per cent. This amount, while dangerous, may, if carefully flooded, admit of several crops being grown before the ground water is raised sufficiently to injure the land permanently. This acreage of less than 0.60 per cent is alone enough to make of the area quite a wealthy agricultural district, alkali-resistant crops being grown on the worst lands, and other crops suited to the climate on those less alkaline and sandy enough to allow intertillage and the deep penetration of the roots.

It is highly probable, however, that the next few years will see an entirely new system of agriculture for these lands. Date palms for the delta have long been talked of, and the Department of Agriculture is experimenting with these in the Southwest, with every indication of success. There is hardly any land on the desert that will not grow these if the climate is suitable, so that this crop may be the ultimate solution of the alkali problem for much of the desert.

The soil is wonderfully fertile, and, irrigated with the sediment-laden water of the Colorado, must remain so. The ultimate total reclamation and profitable cultivation of the desert will surely take place. The greatest question at present is one of expediency, namely, How can the reclamation take place and yet protect the present owners from loss? It is believed this can best be done by cultivating at present only the lands that will produce profitable yields of the crops now being grown and by leaving the badly alkaline lands to be reclaimed when a new system of agriculture has raised the price of land to a point where it will justify the expenditure and when the need for reclamation has been recognized by everyone interested in the country, so as to secure a complete cooperation of all concerned.

In the summer of 1904 the Reclamation Service of the U. S. Geological Survey made a study of the crops of the region. This study showed 31,318 acres in crops. Of this amount 30,012 acres received sufficient irrigation, and 1,306 acres were insufficiently irrigated. Three hundred and thirty-seven acres of good crops were produced; 18,425 acres were fair; and 1,125 acres were poor crops. Not all of the failures were due to alkali, but a trip to the district in November, 1904, showed that the greater part was unquestionably due to the presence of excessive quantities of alkali.

The salts of the basin are all of the white alkali variety—principally chloride of sodium. Appended is a table showing a number of analyses of the alkali of crusts and soils from the basin:

Chemical analyses of alkali soils and subsoils.

Constituent.	8030.	8031.	8032.	8033.	8034.	8035.	8036.	8037.	8038.	8039.
	NE. cor. sec. 15, T. 16 S., R. 12 E.	NE. cor. sec. 11, T. 17 S., R. 13 E.	Subsoil of 8031.	E. side 3-40 sec. 33, T. 11 S., R. 14 E.	NE. cor. sec. 1, T. 15 S., R. 15 E.	Subsoil of 8034.	One-fourth mile W. of Volcano.	Subsoil of 8036.	NW. cor. sec. 18, T. 11 S., R. 14 E.	Subsoil of 8038.
Ions:	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
Calcium (Ca)	11.26	15.63	12.57	2.21	7.05	6.61	7.83	9.09	6.91	3.11
Magnesium (Mg)	3.15	2.91	1.92	1.10	2.86	3.23	2.30	3.66	2.02	2.74
Sodium (Na)	11.71	11.88	17.18	27.15	26.08	23.82	24.82	20.21	24.77	26.58
Potassium (K)	4.96	2.29	3.27	1.93	.36	1.32	.87	1.00	1.70	1.59
Sulphuric acid (SO_4)	31.54	24.59	26.24	32.14	7.60	14.27	15.67	24.17	23.20	32.16
Chlorine (Cl)	15.77	32.70	36.72	15.52	55.27	45.46	47.39	39.92	39.79	29.84
Bicarbonic acid (HCO_3)	21.61	10.00	2.10	19.95	.78	5.29	1.12	1.95	1.61	3.98
Conventional combinations:										
Calcium sulphate ($CaSO_4$)	38.32	34.78	37.17	7.48	10.75	20.15	22.21	30.91	23.47	10.54
Calcium chloride ($CaCl_2$)	......	15.00	4.50	......	10.80	1.91	3.62	......	......	......
Magnesium sulphate ($MgSO_4$)	5.85	......	......	5.26	......	......	......	2.95	8.30	13.64
Magnesium chloride ($MgCl_2$)	7.20	11.47	7.54	......	11.21	12.65	9.04	11.99	1.39	......
Sodium sulphate (Na_2SO_4)	......	......	......	33.51	......	......	......	......	......	20.46
Sodium chloride (NaCl)	9.45	20.39	41.68	22.72	65.48	55.59	61.95	49.60	61.41	46.86
Potassium chloride (KCl)	9.45	4.61	6.25	3.60	.70	2.50	1.65	1.89	3.23	3.01
Sodium bicarbonate ($NaHCO_3$)	29.73	13.75	2.86	27.43	1.06	7.20	1.53	2.66	2.20	5.49
Per cent soluble	.45	.96	3.42	.72	7.69	1.16	6.41	3.38	4.46	2.26

INDIO AREA, CALIFORNIA.

In 1903 a soil survey was made of the area about Indio, Cal., by J. Garnett Holmes. This area is situated at the upper end of Salton Sink and is separated from the Imperial country by the broad expanse of the low, moist, salt-bearing portion of the sink. The climate of the two areas is practically the same. There is a great difference, however, in the soil and alkali conditions.

This question is discussed in the report made upon this area, as follows:

> The gravity of the alkali problem in any arid country is dependent upon the amount and kind of salts in the soil, the amount of salt in the irrigation water, and the drainage of the country. Drainage may be taken to include not only the drainage of the country as a whole, in the sense of being free from excessive amounts of ground water, but drainage within the soil itself—the rate at which the water leaches through the soil.
>
> The alkali map which accompanies this report shows much of the valley to contain excessive amounts of alkali. To the uninformed observer this would seem to be a very grave state of affairs, for some of the percentages shown on the map are too great to permit the growing of many of the common crops. This alkali, however, is all at or near the surface of the soil. Here there are no deep-seated alkali deposits, the ground water all over the valley is of good quality, and no alkali is found below the ground water. Since the ground water is nearly always near the surface the soil lying above the water table (except in the lower levels) contains practically all the alkali in the vertical section of soil. About the Salton Sink the ground water has taken up enough salt from lateral percolation through alkali lands above to be quite salty.
>
> The ground water comes from heavy rainfall and melting snows in the mountains surrounding this part of the basin. The waters of old Whitewater River, which flowed into the bay when this was an arm of the sea, disappear in the sands near Indio and find their way to the sink through subterranean channels. Thus there is a continual stream of underground water passing through the soils of the valley. For this reason the valley may be said to have poor regional drainage, while the drainage of the soil itself, its permeability, is very good.
>
> The slope of the country mapped is on an average 12 feet to the mile, and for that part between Walters and Indio it is nearly 20 feet to the mile. With the coarse soils and heavy grades there would be no trouble about drainage if it were not for the steady stream of underground water flowing through the soil. This has been the source of all the alkali trouble. It has come so near the surface that in the trough of the valley evaporation from the surface has alkalied a considerable part of the lands. Since the drainage in the soil itself is good, the obvious thing to do is to devise some means of carrying off this ground water more quickly than is the case where it leaches through the soil. If the water table could be permanently lowered, the soil generally would not need to be drained artificially, and one or two heavy floodings would so reclaim the worst soils that alkali-resistant crops could be grown. All that is necessary is to lower the ground water and flood the surface, being careful to cultivate the soil as soon as possible after each wetting, so as to prevent the evaporation of water from the surface and the deposition there of the alkali carried in solution.
>
> The best method of draining the valley can be determined only after careful surveys, but in all likelihood a long, deep, open ditch running down the center of the valley, with lateral ditches on both sides, would be sufficient to keep the general level of the ground water below 6 feet.
>
> Whatever the method adopted for the general drainage and reclamation of the lands of the valley, the individual farmer will be dependent upon his own knowledge and resources for the reclamation of his own particular field. In this reclamation work he should keep

in mind the well-established principle that alkali follows the water until evaporation takes place. His energies should be devoted to the prevention of evaporation from the surface of his land, for it is at the surface that alkali does most damage to young and tender plants. The best method of getting alkali out of the land is by heavy surface flooding. Except where the water table comes to within 6 feet of the surface the land of the valley can be entirely reclaimed in this way. The alkali being washed into the subsoil and kept there by preventing surface evaporation will eventually be carried away by the stream of subterranean water.

Flooding without drainage, while it betters the lands lying at higher levels, can not fail to be detrimental to lands lying at a lower level. Since a comprehensive system of reclamation, to include the whole of the valley, is so simple and can be placed in operation so cheaply, it seems a very unbusinesslike procedure to injure one part of the valley in order to better another part when all might be permanently reclaimed.

The greatest obstacle to reclamation is the comparatively small head of water at the command of individual landowners. All the water is from artesian wells, and irrigating is done only on a small part of the farm at one time and usually by the furrow method. The capacity of the wells is not great enough to flood very much of the open, sandy soil. The porous nature of the soils makes it almost impossible to combine the flow of wells situated at some distance from one another. This state of affairs can no doubt be remedied by making larger wells, which will be capped and allowed to flow only when the water is needed for irrigation.

When the land is flooded the greatest care should be taken to have all the surface leveled. Any hummocks or ridges extending above the water will furnish points from which the water will evaporate, and the current, instead of being wholly downward, will be partly toward the surface, and much of the alkali washed from the soil in the immediate vicinity will be deposited on these high spots.

After the land has been partially reclaimed, furrow irrigation may be practiced, as this method is much more economical of water, and the crops adapted to this valley, such as melons, grapes, truck, etc., are more easily irrigated in this way. Where furrow irrigation is practiced, care should be taken to have the furrows as deep as practicable without injuring the plants and to cultivate the soil as soon as possible after irrigation. When ridged crops, such as sweet potatoes and melons, are grown, borders should be thrown up, dividing the field into lands, and these lands should be flooded after the crop has been harvested, the surface being cultivated immediately afterwards. This flooding may not be necessary every year, but in any other method of irrigation than flooding a periodical flooding is necessary in order to wash into the subsoil the small amount of surface accumulation of salts that are found in even the most carefully cultivated fields.

If ordinary care is exercised in the cultivation of the lands of this valley, there is no reason why they should not become steadily better, until even the most sensitive crops can be grown and trouble from alkali ceases entirely.

KEARNEY AREA, NEBRASKA.

The Kearney area was surveyed in 1904 by J. O. Martin and A. T. Sweet. It includes that part of the Platte Valley in south-central Nebraska lying between the ninety-ninth and one hundredth meridians of west longitude. The area contains about 792 square miles. The climate is typical of the great semiarid plain east of the Rocky Mountains, the annual rainfall being about 20 inches. The topographic features of the area consist of a broad, flat valley floor bordered on each side by a dissected upland plateau. The soils in the valley proper represent reworked materials laid down by the Platte River.

The soils of the uplands are weathered glacial débris, in many respects resembling loess. Water for irrigating purposes is taken from the Platte, but owing to the abundant rainfall for several years preceding 1904 there had been but little need of irrigation. The water table lies at distances from the surface varying from a few feet to about 40 feet. There are generally two veins of water, the upper one containing the higher percentage of soluble salts.

Beginning at Odessa and stretching westward there was found an area in which much of the soil contained enough alkali to be injurious to crops. For the most part the alkali spots lay to the north of the Platte River. These alkali areas grew larger and more numerous toward Lexington, beyond which they gradually diminished in size and number, so that the worst affected areas were found between Lexington and Overton. South of the Platte, near Lexington and Cozad, areas of alkali land were also found.

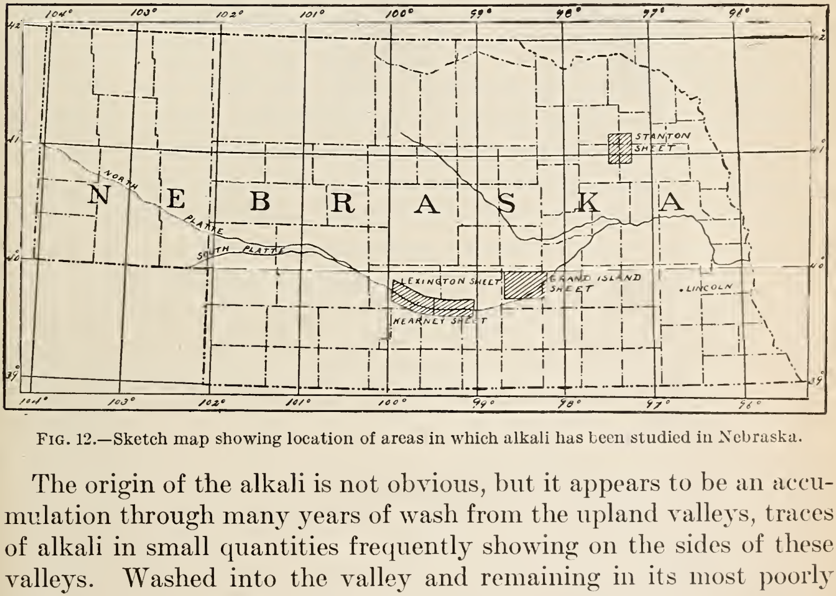

FIG. 12.—Sketch map showing location of areas in which alkali has been studied in Nebraska.

The origin of the alkali is not obvious, but it appears to be an accumulation through many years of wash from the upland valleys, traces of alkali in small quantities frequently showing on the sides of these valleys. Washed into the valley and remaining in its most poorly drained portions, these small quantities are concentrated by evaporation during the dry seasons. The ground water also becomes impregnated with alkali to a greater or less degree and, where it is near the surface, becomes a continuous source of supply.

The chemical composition of the alkali in these areas is quite variable. It consists mainly of salts of sodium, potassium, and calcium, with some magnesium in various combinations. From analyses it was found that sodium and potassium salts predominated. The distribution of the alkali in the soil was very irregular, as scarcely any two vertical sections gave the same results. At the time the examination was made the season had been unusually wet, and this may have had a great deal to do with the irregular distribution of the alkali in the soil.

All of the lower valley soils would be benefited by drainage, but the fall is so slight that the drainage of individual tracts would be difficult, and the result could best be accomplished by the construction of large public or corporate ditches into which individuals could discharge their drains.

GREELEY AREA, COLORADO.

In the summer of 1904 a soil survey was made by J. Garnett Holmes and N. P. Neill, of the Cache la Poudre Valley (Greeley area) in northern Colorado. This survey includes parts of Larimer and Weld counties.

The area surveyed lies at an elevation of between 4,000 and 5,000 feet. Rainfall is insufficient to grow a wide range of crops, but with careful cultivation should be sufficient for fair crops of grain or other drought-resisting cultures. The summers are cool and pleasant. Winter temperatures of 40° F. below zero are reported. The whole country is a rolling, undulating prairie, the only land that even approximates a level surface being the small valleys along streams and creeks. With the rainfall and the generally rolling surface no accumulations of alkali should have occurred if ordinary precautions to insure drainage for the level valley floors had been taken. Shortly after irrigation began, however, these lower valley areas were allowed to become swamped, and a consequent accumulation of alkali has occurred in many of these lands. Practically all the soils are leachy and porous, permitting much seepage from ditches and irrigated fields. This seepage water rapidly accumulates in the lower soils, greatly raising the entire water table of the region, but actually damaging none but these lowlands. Sufficient drainage to carry away the surplus water from these lowlands, with a few heavy floodings, should rapidly bring all the damaged lands again into a high state of fertility. This is being done in many instances, and already many acres have been reclaimed. The building of beet-sugar factories at several points in the valley has made the growing of sugar beets a very profitable business, and since the accumulation of alkali has rarely reached such a state that this crop will not grow if the surplus ground water is removed mere drainage is often sufficient to bring the lands into such a condition as to be immediately valuable.

The common practice in draining is to make a three-sided box or trough of pine boards, which is used as a drain, being placed at the greatest possible economical depth. The water developed from these drains is used at lower levels for irrigation. The alkali is all of the white variety, in which there is much gypsum. It is the common belief among those having experience that this gypsum would fill the pores and joints of drain tile and render them inoperative. Board drains as described above are cheap and efficient and if well installed give no trouble. All of the lands in the valley now considered too alkaline to grow crops can be thus cheaply and profitably reclaimed. The people are interested, and no doubt the work will receive great extension.

BEAR RIVER VALLEY, UTAH.

The Bear River area was surveyed in 1904 by Charles A. Jensen and A. T. Strahorn. Bear River Valley lies in north-central Utah. The area includes practically all the irrigable land in the valley within the State, and also part of the former bed of Great Salt Lake. The climate of the area is semiarid, having an annual rainfall of nearly 12 inches at Corinne. The surface features of the area fall into three divisions: The cultivated mountain slopes on the east and west sides of the valley; the low-lying flat bottom lands formerly covered by Great Salt Lake in its concentrated condition; and the higher lying and level prairie lands north of the lake-bottom lands and included between the mountains. The soils consist principally of former lacustrine deposits, including many loam and sandy loam soil types. Water of excellent quality for irrigating purposes is taken from Bear River.

The extent of the various areas of underground water during the progress of the survey, in 1904, is shown in the following table:

Areas of underground water.

Depth.	Acres.	Per cent.
Less than 3 feet deep	64,640	30.3
From 3 feet to 6 feet deep	57,216	26.7
From 6 feet to 10 feet deep	39,808	18.6
Over 10 feet deep	51,968	24.3
Total	213,632	....

The underground water is often very salty. This is especially true of the level area north and west of Corinne. The surface well waters examined contained from 150 to 500 parts of salts per 100,000 parts of water. These salts consisted principally of chlorides, with some bicarbonates and from 3 to 20 parts of alkaline carbonates, or black alkali. Sulphates were not often present. The deeper-seated waters are more salty, generally, than the surface well waters, especially west of Bear River. The underground water along the east side of the valley is very good, containing very little alkali. There are many salty springs in the area, especially at the south end and west side of Little Mountain. These contain from 2,000 to 3,000 parts of salts per 100,000 parts of water.

One of the best indicators of future alkali conditions is the position of the underground water table. As will be seen from the above table, this water is already dangerously near the surface, especially in the western part of the valley. Drainage of much of this land will be necessary in order to render this as yet virgin land suitable and safe for cultivation. Drainage systems for this kind of land must necessarily be quite comprehensive in scope, and it would generally be impracticable for individual farmers to drain isolated farms, unless their lands are adjacent to the natural sloughs that traverse some parts of the area.

The actual and relative extent of the various grades of alkali soils, as determined during the progress of the survey, are given in the following table:

Areas of alkali land.

Grade.	Acres.	Per cent.
Less than 0.20 per cent	75,584	35.4
From 0.20 to 0.40 per cent	11,648	5.5
From 0.40 to 0.60 per cent	8,000	3.7
From 0.60 to 1 per cent	14,528	6.8
From 1 to 3 per cent	25,280	11.8
Over 3 per cent	78,592	36.8
Total	213,632	....

The alkali areas were located in the southern, western, and southeastern parts of the area surveyed, extending from 4 to 6 miles in all directions from Little Mountain. The only areas entirely free from alkali were in the northern end of the valley. The areas of greatest salt content were located chiefly in what was formerly part of Great Salt Lake and in the bed of Box Elder Lake. In these areas the average salt content for the first 6 feet is anywhere from 3.50 per cent to 10 per cent. All the alkali in the area owes its origin to the process of lake recession and concentration.

The alkali is composed principally of chlorides, by far the largest constituent being sodium chloride or common salt. There are also limited quantities of alkaline carbonates and hydrogen carbonates, but sulphates are very seldom found. The alkaline carbonates (black alkali) were found practically everywhere in very small quantities in both soil and subsoil, but with one or two exceptions tests showed less than 0.05 per cent. There are many local black looking alkali spots throughout the area that are commonly supposed to be chiefly alkaline carbonates, but tests never showed more than traces, the principal constituents being chloride and some bicarbonates. Generally the maximum salt content was found in the third or fourth foot section, but sometimes as deep as the sixth foot.

On account of the fact that the surface soil to a depth of 1 or 2 feet is very often comparatively free from alkali, a native growth of sagebrush, rabbit bush, flowers, and grasses often prevails where the average salt content for the first 6 feet of soil is from 1 to 3 per cent. By these conditions the people are often led to believe the soil is free from alkali. Where, however, such vegetation as young greasewood, samphire, salt grasses, etc., predominates, the alkali is not far below the surface.

Some data were obtained concerning the amount of alkali that crops in the valley would withstand. As the alkali conditions change more or less during the growing season, owing to surface evaporation, irrigation, etc., the data can not be regarded as absolute. Young wheat was found doing well with from 0.50 to 0.56 per cent of salt in the surface foot, and oats, while not doing so well, would apparently mature nicely.

During the spring, when sugar beets were young, tests were made at the root crowns of beets that seemed to be growing in their limit of alkali, and 1.52 per cent of soluble salt was found in the first foot. No examination of the second foot was made. Late in the summer the same field was visited, and it was found that beets were growing well and would mature in soil carrying from 2.50 to 4.70 per cent in the surface foot, with 0.42 to 0.84 per cent in the second foot. These were isolated beets growing in alkali spots that had killed out most of those planted. As the surface foot of soil carried more salt in late summer than in spring, when the field was first examined, and as the beets were well able to mature, it would seem that 1.50 per cent of alkali in the surface foot was not more than beets could endure. The fact that sugar beets were found growing in such a high percentage of alkali seems at first sight somewhat strange, but the amount of alkali in which a crop is found growing at any one time tells very little of the life history of that crop. Because sugar beets were found growing in from 2.50 to 4.70 per cent of alkali in the surface foot of soil late in summer does not argue that the same sugar beets would have been able to resist such quantities in their younger stage, and in fact they did not do so.

A heavy, well-matured crop of alfalfa was found growing in soil containing 0.14, 0.27, 0.43, 2.00, 3.12, and 3.75 per cent of alkali from the first to the sixth foot, respectively—an average of 1.62 per cent—with standing water at 4 feet. The water table was probably temporarily high owing to recent irrigation.

Owing to the recession of Great Salt Lake large areas of lake bottom land were found in the southern and southwestern parts of the area surveyed. The water was within 2 or 3 feet of the surface and the soil was excessively salty, containing more than 3 per cent in the first foot, with increasing amounts at greater depths. However, large tracts of this land support a heavy crop of sedge grass wherever Bear River overflows it copiously during the late winter and spring. Tests in heavy growths of this sedge showed from 3 to 5 per cent of alkali in the first foot, with increasing salt content in the subsoil. Large quantities of this grass are harvested for winter feed, and, while not a choice hay, it is fed to cattle until spring. Other grass is grown in small quantities on the same land, which makes it valuable for summer grazing. The following varieties, which were determined by Professor Spillman, promise to be of considerable value for such land: *Distichlis spicata*, *Polypogon monspeliensis*, *Scirpus maritimus* (sedge), and *Puccinellia airoides*. The last-named grass should be cultivated in preference to the coarse sedge, as it is much more valuable for feeding, though the yields are not so large.

BAKERSFIELD AREA, CALIFORNIA.

The Bakersfield area was surveyed in 1904 by Macy H. Lapham and Charles A. Jensen. It is situated near the extreme southern or upper extremity of the San Joaquin Valley. A considerable acreage is devoted to the growing of alfalfa, grains, vines, live stock, and dairy products.

The climatic conditions here approach closely those of a desert, with high summer temperatures, low relative humidity, and other climatic conditions promoting excessive evaporation.

The largest and most important part of the area consists of the Kern River delta deposits, composed largely of mountain wash of granitic material. In general the physiographic features resemble the Kings River delta, but the area slopes somewhat more abruptly to the southwest and lacks many of the open sloughs and stream channels. While the natural drainage slopes over the greater part of the area are sufficient readily to remove surplus waters, a few parts of the area, especially in the vicinity of the southeastern and southwestern margins, are deficient in natural drainage and heavily impregnated with alkali. The prevailing soils are sands and sandy loams, generally of fine texture, micaceous and porous. In the vicinity of the city of Bakersfield and along the eastern margin of the area a few soil types having adobe and heavy loam subsoils occur. All the soils of the area are, however, in general underlain by light and porous subsoils. Capillary and gravity movement of soil waters take place readily, especially in the fine micaceous sands frequently occurring in irregular or elongated, slightly elevated bodies or ridges.

No attempt is made to produce crops without the aid of irrigation. The water supply, which is taken from Kern River, with, in a few cases, an auxiliary supply derived by pumping from deep wells, is of excellent quality, but owing to the uncertain and limited supply a large proportion of the lands within the area surveyed are unirrigated and barren.

In the aggregate a large percentage of the soils of the area contained alkali salts in such quantities as to render them practically worthless for agricultural purposes. The alkali was distributed as irregular patches, bodies, and streaks, occurring chiefly upon the fine micaceous soils and river sediments of the delta lands lying south of Kern River. The slightly elevated ridges and patches of porous micaceous fine sands are especially liable to impregnation, possessing marked capillary properties, which under the influence of rapid evaporation quickly restores the bulk of the salts to the surface from the moist subsoils, into which they find their way as they are leached by irrigating waters from adjoining low-lying areas of soil. These minor elevations, lying above the reach of the irrigating waters, which are here applied by surface flooding and not by subirrigation, as in the Hanford area, thus become strongly impregnated with salts, which under the normal rapid upward movement in response to evaporation from the surface form a heavy crust or loose pulverulent alkali mulch, consisting of a mixture of soil grains and salt crystals, at or near the soil surface. The subsoils were, however, throughout the lighter soils of the area, frequently comparatively free from salts, even when salts occurred in the surface foot in concentrated form. In the vicinity of the eastern margin of the area surveyed, however, soil types occur of heavier texture, in which the alkali salts appeared in concentrations of from 1 to 3 per cent or over to the depth of 6 feet, or concentrated in a lime-carbonate-alkali hardpan encountered in the subsoils. Sodium carbonate, or black alkali, is of common occurrence in the Bakersfield area, and in fact seems to be of general occurrence whenever alkali salts in considerable amounts occur throughout the eastern side of the San Joaquin Valley. Frequent exceptions to this rule were to be found, as in the silt loam soils occurring southeast from the city of Bakersfield, which carried enormous quantities of alkali salts, chiefly of the sodium chloride variety, but were free from the more destructive carbonates.

There are no unusual or untoward conditions favoring the formation and presence of alkali salts in this area. In such regions of deficient rainfall and resulting restricted drainage the formation, by weathering of rock particles, of alkali salts in excess of the amount removed by scanty rains and flood waters is of general occurrence. In this area climate and topography do not favor the rapid removal of these substances. In fact, owing to the absence of more or less complete natural drainage channels, the soils are not favored by natural drainage facilities. Irrigation has here also resulted in the saturation of the subsoils and the raising of the water table. This, with the porous soils, capable of rapid capillary movement, furnishes sufficient cause for the concentration of alkali salts in the surface of slightly elevated porous soils which irrigation water does not reach and in the heavier soils and subsoils of sinks or local drainage basins. Furthermore, but little of the area is devoted to the growing of cultivated crops, which by frequency of cultivation tend to check evaporation and prevent the rise of the alkali salts. Upon the other hand, owing to the limited supply and to the greater cost of procuring and applying irrigating waters, greater enforced economy in the use of water is practiced.

While enormous quantities of alkali salts occur within the area, the most serious concentrations occur usually upon either those soil bodies of slight elevation which lie above the reach of the irrigating waters or else in more extensive tracts which are uncultivated and unirrigated for lack of water.

With the exception of a few cases in which heavy subsoils of dense structure occur, the salts seem to be leached readily into the porous subsoils with a few generous floodings and removed by natural drainage. Concentration contour lines are thus frequently very abrupt and distinct, depending upon the extent and frequency of cultivation and irrigation. A few irrigations and slight preliminary cultivations frequently seem to sweeten the lands enough for ordinary crops, and one may often see alfalfa fields free from alkali salts in any injurious amounts separated from tracts of too great concentration for any ordinary crop by only the width of a public roadway or by a line of fence.

Natural conditions of soil texture, structure, and topography over a great proportion of the area thus favor rapid reclamation of the alkali lands, which is, upon the other hand, opposed by a limited water supply. The opening of a few drainage ditches and the laying of occasional lines of drain tile would aid in removing the excess of salts and tend to permit the use of less water in the first washing of the salts from the soil.

Upon some of the soils of the eastern and southwestern margins of the area, in addition to lack of water supply, there is a deficiency in natural drainage. Were water available for irrigation and reclamation, the opening of a more extensive system of drainage, with the construction of extensive drainage ditches and perhaps the improvement of one or two incomplete natural drainage channels, would here be necessary in order to render the heavily impregnated alkali soils productive.

CANDO AREA, NORTH DAKOTA.

The Cando area was surveyed in 1904 by Elmer O. Fippin and James L. Burgess. This area is situated in the northeastern part of the State and contains 288 square miles. After the land was opened for settlement in 1883 the development for a period of years was quite rapid, but a succession of disastrous crop failures in the late eighties retarded the development. Since that time there have been favorable crop seasons and the area has become quite prosperous.

The average annual rainfall amounts to nearly 20 inches, the greater part of which falls during the growing season. The country consists of an undulating treeless prairie, slightly trough-shaped, with the lowest portion forming a broad, shallow valley. The elevation above sea level is approximately 1,500 feet, with a general southward slope.

The soils of the area are chiefly derived from glacial débris and consist principally of loams, with smaller areas of clay and fine sandy loam soils. As a rule, all of the soils of the area are quite rich in organic matter. Except in a few instances, alkali conditions are not serious and with proper methods of soil management will never seriously affect the productiveness of the soils. The rainfall is sufficient to prevent any marked accumulation of salts within the root zone of the soil. The accumulation of alkali salts that occurs is confined mainly to local spots in small depressions or in somewhat larger areas of poor drainage. The salts found in such places have been leached from the soil of higher-lying areas by the rain and retained there through obstructed drainage. Most of the salts in the Cando area are sulphates, analyses of the moist alkali spots revealing no sodium carbonate. The sulphates of calcium, potassium, magnesium, and the bicarbonates of the last three constitute the principal salts. Slight amounts of sodium chloride were also found.

To reclaim the worst alkali accumulations along the sloughs and coulées, surface drainage should be resorted to wherever possible. Underdrainage is usually impracticable, and in most cases unnecessary, because the only requisite is that the salts be kept below the zone of root action, and good surface drainage, with deep and thorough cultivation, accomplishes this result, since most of the crops grown are shallow rooted.

LABORATORY INVESTIGATIONS BY THE BUREAU OF SOILS.

In addition to the field investigations carried on by this Bureau considerable work has been done in its laboratories upon the relations of alkali and soils.

SALTS AS INFLUENCING THE RATE OF EVAPORATION OF WATER FROM SOILS.

Briggs[a] has investigated the effect of sodium chloride, sodium sulphate, and sodium carbonate in modifying the rate of evaporation of water from soils.

Three sets of experiments were made, as follows:

(1) The evaporation from moist soils spread out in thin layers in large trays was measured, some of the samples being moistened with normal salt solutions and others with distilled water to serve as

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[a] Field Operations, Div. of Soils, 1899, Report 64, Dept. of Agr., pp. 184–198.

checks. The soil in all the trays was stirred frequently in order to prevent the formation of any crust of salt. The object of this experiment was to determine whether the marked diminution of evaporation from alkaline soils, observed by Buffum, was due to surface conditions.

(2) The relative rate of evaporation in open dishes of pure water and of saturated solutions was measured as a check upon the conditions in the preceding experiment.

(3) The evaporation from the surface of soils packed in tall, narrow cylinders and moistened with pure water and with normal salt solutions was measured. This was a repetition of Buffum's experiments. This arrangement served to accentuate the formation of salt crusts at the surface. The soil used in all the experiments was a fine sand from James Island, S. C.

The results of the first experiment show that the soils moistened with normal solutions of salts lose their water by evaporation nearly as rapidly as soils moistened with distilled water, provided the soil is stirred occasionally, so as to prevent the formation of surface crusts. The evaporation from soils moistened with normal solutions of sodium chloride, sodium sulphate, and sodium carbonate was about 10 per cent less than when distilled water was used.

The results of the second experiment show that the evaporation from saturated salt solutions, in Petri dishes, averaged about 10 per cent less than evaporation from distilled water under similar conditions. These results agree well with those in the preceding experiment, showing that the diminution in evaporation under the conditions employed in that experiment was not influenced by the fact that the solutions were distributed over the surfaces of soil grains.

The results of the third series corroborated those of Buffum, showing that evaporation from soil columns moistened with normal salt solutions was only from 50 to 60 per cent of that from the cylinder moistened with distilled water. The results of the two preceding experiments show that this effect is much greater than can be attributed to the physical properties of the solutions, and that the greatly diminished evaporation in this case must be attributed to the formation of the crust of salt on the surface of the soil, which acts as a mulch.

For purposes of comparison, the evaporation was also determined from a cylinder moistened with distilled water but covered with a mulch of sodium sulphate. The evaporation from this cylinder was practically the same as from the cylinders in which the soils were moistened with solutions, showing again that the evaporation is controlled mainly by the surface conditions.

The conclusion drawn from these experiments is that the rate of evaporation from saturated solutions from the more common alkali salts is about 10 per cent less than in the case of distilled water, and that this is not changed when the solutions are distributed over the surface of soil grains, provided no crust is allowed to form during evaporation. When, however, evaporation takes place from an undisturbed column of moist soil containing a considerable quantity of salt solution the accumulation of salt at the surface acts as a mulch, which cuts down evaporation to about one-half of that taking place from a similar column of soil moistened with distilled water. The rate of evaporation is, therefore, in the case of alkali soils, dependent much more upon surface conditions than upon the physical properties of the salt solution. This statement must not be considered as applying to diminution of evaporation resulting from the formation of hardpan in the soil mass, which obviously depends upon the nature of the substances in the solution.

CAPILLARY STUDIES.

Briggs and Lapham (Macy H.)[a] have investigated the influence of the concentration of the soil solution upon the capillary rise of soil moisture.

Soil columns were held in glass tubes 2½ cm. in internal diameter, supported upon disks of fine brass wire gauze cemented to their lower ends. The lower end of each tube was immersed in the salt solution, the solution in each case being maintained at a definite level by a modified Mariotte apparatus. The salts investigated were sodium chloride, sodium carbonate, and sodium sulphate, and three concentrations of each were used, namely, one-half normal, 20 per cent, and saturated. In the case of the one-half normal solutions (corresponding to from 2.5 to 3.5 per cent by weight, depending upon the salt used) the height to which the solutions rose was practically the same as for distilled water. The capillary rise for saturated solutions of the sodium chloride and sodium sulphate was but little more than half of that observed for the one-half normal solutions. Sodium carbonate solutions in both cases rose higher than the solutions of the other salts. The actual rise observed for the fine sand in the case of the one-half normal solutions was about 37 cm. for sodium chloride and sodium sulphate and 40 cm. for sodium carbonate, while in the case of the saturated solutions the sodium chloride and sodium sulphate solutions gave a capillary rise of 21 cm. and the sodium carbonate solution 30 cm. The capillary rise of distilled water in this soil was 37½ cm.

Briggs and Lapham summarize the results of their paper as follows:

(1) Dissolved salts in general do not increase the capillary rise of soil waters.

(2) Neutral salts in dilute solutions have practically no influence on the extent of capillary action.

(3) Concentrated or saturated solutions of all salts materially diminish capillary activity.

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[a] Capillary Studies, Bul. 19, Bureau of Soils, pp. 5–18.

(4) This effect appears to be due—

(*a*) To the increased density of the solution, which more than offsets the increased surface tension; and

(*b*) To the resistance of a film to a tangential shearing stress, which retards capillary action and offers in addition a permanent resistance to the movement of the solution through thin films, thus increasing the angle of contact; or

(*c*) To an increase in the tension of the liquid-solid surface as the concentration is increased.

(5) Sodium carbonate differs from neutral salts, the capillary rise being considerably greater than for neutral solutions of equal concentration.

(6) This may be due in part to the saponification of traces of grease on the surface of the soil grains through the hydrolysis of the sodium carbonate, thus furnishing clean surfaces for capillary action.

(7) The same effect should consequently be observed with all salts which undergo an alkaline hydrolysis, viz, potassium and sodium carbonates, borates, phosphates, etc.

(8) This action is characterized in the soil tubes by indistinctness of the upper boundary of the capillary column.

The marked diminution in the capillary rise as the concentration increases serves to protect the soil to some extent from the accumulation of salt at the surface. The effect is then in the same direction as that found by Briggs in his experiments on the influence of dissolved salts on the rate of evaporation of soil moisture (see p. 139), where the rate of evaporation was shown to decrease as the accumulation of the salts at the surface increased. Too much weight must not, however, be placed upon these experiments made with dry soils, as Briggs and Lapham have shown (see p. 143) that the height through which capillary action will take place in a moist soil is much greater than the capillary rise in a dry soil.

A great number of experiments have been made upon the height to which water will rise by capillary action in different types of soils, and the results of such experiments have been used as a basis for computing the distance through which a given soil can lift water by capillary action from the water table to the surface. Such experiments have also been used in calculating the depth below the surface at which tile-drains must be placed in order to prevent capillary connection between ground water and the surface. However, Briggs and Lapham[a] have shown that the height through which capillary movement of water will take place in a moist soil as a result of evaporation at the surface is much greater than the height to which water will rise by capillary action in a dry soil and that, consequently, measurements made upon dry soils are inadequate for determining the height through which the soil can supply water to the roots of plants or the depth to which tile must be placed in order to cut off effectively the capillary connection between the water table and the surface of the soil. The true limit for capillary movement may be determined by finding the limiting height of the soil column from the upper surface of which evaporation is taking place at a measurable and approximately uniform rate, water being supplied at the same time from a reservoir at the base of the column of soil. For a fine sand it was found that the capillary rise in a dry soil was only 37 cm., while the limiting value of the capillary movement in a vertical column of moist soil was not less than 165 cm., or four and one-half times as great.

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[a] Capillary Studies, Bul. 19, Bureau of Soils, 1902, pp. 19–30.

NATURE OF SOLUTIONS.

Chemical analysis of the soluble salts found in arid regions yields rather remarkable results, for there is found a relatively large percentage of salts which are usually regarded as sparingly soluble—notably the sulphate and the carbonate of lime—and the question how they have been dissolved and transported in such large quantities is a natural one. When we attempt to dissolve these salts in water, in order to remove them from the soil, just such surprising solubility results are obtained, and in order to understand these phenomena it will be desirable to review the solution laws which apply to these cases.

Before discussing these laws it seems well to state more precisely what is understood by the term "solution," and as we are concerned only with solutions of solids in liquids we shall not stop to make any modifications which other solutions would necessitate.

The most striking characteristic of a solution is its homogeneity; that is to say, after it has come to equilibrium every part of the solution is just like any other part in all its physical and chemical properties. Two important exceptions should be noted here. If the solution be one of considerable height or depth the gravitation force comes in evidence, the lower portions of the solution are more dense, the higher portions less so, and there is a corresponding variation in other properties. But there is no sudden break in the properties, for they vary regularly and continuously from the top to the bottom. Again, it has been observed in the case of solutions in contact with solids (the walls of the containing vessel, for instance) that in portions very near the surface there is often a concentration of the dissolved material. This phenomenon has been called adsorption. Another important characteristic of a solution is that all its properties vary continuously with the concentration. These two properties just described are incorporated in the best definition as yet proposed for a solution, i. e., a homogeneous mixture whose properties vary regularly with the concentration.

It has been found convenient in discussing solutions to introduce certain terms, and, as it will greatly simplify what is to follow, they are here defined. The substance in which the solution takes place is known as the *solvent*, and the substance which goes into solution in the solvent is called the *solute*.

From the study of the phenomenon presented by solutions it has been shown that the solute is in a condition analogous to the gaseous condition, and just as a gas exerts a pressure on the walls of a containing vessel so a solute exerts a pressure on the walls of a containing vessel, through which the solvent is free to move. As the solute can not penetrate the walls of the vessel the tendency to equalize the conditions outside and inside the vessel must result in the passage of the solvent from the dilute to the more concentrated solution. The pressure which must be applied to a solution in order to prevent such a change in concentration is the *osmotic pressure*, and this osmotic pressure is found to be very nearly the same in amount as the vapor pressure would be at the particular temperature if the substance were a gas at that temperature. As the same law governs volume, temperature, and pressure of all gases irrespective of the nature of the gas, the obvious explanation advanced is that the structure of all the gases is quite similar, an explanation which is at the basis of the molecular theory. Thus equal numbers of molecules of different gases are supposed to occupy equal volumes, and hence the volume-pressure-temperature relations are dependent only upon the number of molecules involved.

Some of the properties of gases have been ascribed to solutes. The molecules of the solute are supposed to move freely among one another and to be independent of any specific characteristic of the molecule itself, and consequently they will move or diffuse throughout the solvent until the solution becomes homogeneous. In the case of a vessel with walls permeable to the solvent but not to the solute there is a pressure due to the unequal distribution of the molecules of the solute inside and outside the vessel. This pressure is dependent upon the volume, the temperature, and the number of molecules within the vessel, but is quite independent of the chemical nature of the molecule. Thus the laws which hold for gases also hold for solutions if we substitute the term "osmotic pressure" for "vapor pressure."

The solutions with which we most commonly meet, and those which will almost exclusively interest us, are those in which the solvent is water and the solute or solutes are salts; that is, substances formed by the action of an acid on a base. These substances, when dissolved, show wide variations from the laws which have just been described. These variations are, perhaps, best studied by a consideration of the osmotic pressures they exert, which are found in all cases to be higher than was to be expected. Furthermore, these pressures vary with temperature or concentration in a way entirely different from solutions in general. It was first pointed out by Arrhenius that these variations are characteristic of solutions of electrolytes; that is, solutions through which the electric current passes. By making use of a hypothesis which had been advanced by Clausius the phenomena were readily explicable. Clausius was led to assume that when an electrolyte is dissolved in water it separates, partially at least, into components or, as we now say, it dissociates. These dissociated parts are chemical equivalents, and in the act of dissociating develop equivalent amounts of electricity with different signs. Thus sodium chloride would dissociate into sodium, bearing a certain amount of electricity with the positive sign; and a chemically equivalent amount of chlorine, bearing an equal amount of negative electricity. In the notation of chemistry this is expressed:

$$NaCl \rightleftarrows \overset{+}{Na} + \overset{-}{Cl}.$$

In an exactly similar manner sodium sulphate would dissociate as thus indicated:

$$Na_2SO_4 \rightleftarrows \overset{+}{Na} + \overset{+}{Na} + \overset{=}{SO_4}$$

the negative electricity on the group SO_4, or sulphion, exactly equaling the positive electricity on the two sodium equivalents.

Borrowing an expression introduced by Faraday, these dissociated parts *with their electric charges* are called *ions*. When the solution containing ions is put in an electric circuit, the ions bearing the positive charges are attracted to the negative pole of the circuit and the ions bearing the negative charges toward the positive pole, in accordance with the well-known law of electricity.

The chlorine ions on arriving at the positive pole give up their electric charges, thus becoming ordinary chlorine, which escapes as the well-known gas or reacts on the water of the solvent to form hydrochloric acid and oxygen, which escapes as a gas. In a similar manner the sodium ions discharge their electric burdens, thereby becoming ordinary sodium, and immediately react on the water to form sodium hydroxide and hydrogen. It is to be observed, however, that the chemical behavior becomes entirely different as soon as the ions lose their electric charges. The illustration just used indicates that there would be a gradual accumulation of hydrochloric acid at the positive pole and of sodium hydrate at the negative pole. This is what actually happens, as anyone can readily test by drawing off portions of the solution near the poles and analyzing them.

Each of these ions in solution behaves to all intents and purposes as an individual molecule and exerts its influence as such in determining the osmotic pressure in the solution.

Without going into details, it may be said that from an estimation of the osmotic pressure it is possible to determine the number of ions in a given solution. From the conductivity it is also possible to determine the number of ions; and the agreement by both of these methods is of such a character as to make this idea of electrolytic dissociation or ionization a good working hypothesis.

Just as the osmotic pressure of any solution is proportional to the concentration of molecules or ions, so the other physical properties of solutions are proportional to the concentration. By "concentration" we mean the total number of dissociated molecules and of ions per volume unit of the solution. The lowering of the freezing point, the rising of the boiling point, the lowering of the vapor pressure are all directly proportional to the concentration of the solution.

Suppose a solution of a salt, for example sodium chloride, be brought in contact with another salt, such as potassium nitrate. There will then be in the solution not only the sodium chloride and the potassium nitrate, but the ions formed from them, which may be represented thus:

$$\mathrm{NaCl},\ \mathrm{KNO_3},\ \overset{+}{\mathrm{Na}},\ \overset{+}{\mathrm{K}},\ \overset{-}{\mathrm{Cl}},\ \text{and}\ \overset{-}{\mathrm{NO_3}}.$$

But the $\overset{+}{\mathrm{Na}}$ ions and $\overset{-}{\mathrm{NO_3}}$ ions can form sodium nitrate and will form it to a certain extent, so that we shall have this salt also in the solution. In the same way potassium chloride will be formed and the final state of the solution will represent an equilibrium between the solvent water and the various salts and ions which can be formed. It is obvious that the same condition could be obtained by starting with sodium nitrate and potassium chloride; and the equilibrium could be displaced one way or the other by varying any of the constituents. Such a reaction is called *reversible*. Again, sodium chloride in water partially dissociates thus:

$$\mathrm{NaCl} \leftrightarrows \overset{+}{\mathrm{Na}},\ \overset{-}{\mathrm{Cl}}.$$

But if the concentration be altered by the addition or evaporation of water, the equilibrium is displaced and either more sodium chloride will dissociate or more will be formed from the already dissociated ions. In fact, practically all simple reactions so far studied, whether in solution or otherwise, have been found to be reversible.

Suppose a reversible reaction between A and B with the formation of C and D. It may be expressed thus:

$$A+B \leftrightarrows C+D.$$

Let p, q, r, s represent the active masses or the number of molecules per unit volume acting, respectively.

Let K be the rate of combination of unit masses of A and B to form C and D, and

Let K_1 be the rate of combination of unit masses of C and D to form A and B.

The magnitude of the reaction A + B →. is Kpq, for it is directly proportional to the rate of combination and to the active masses, and it will be K_1rs for the reaction C + D →. Therefore when equilibrium is established

$$Kpq = K_1rs. \tag{1}$$

This is known as the law of "mass action," or of Guldberg and Waage. It is conventional to take as the unit of active mass in solutions one reacting weight per liter.

Applying this formula to the case just cited,

$$\mathrm{NaCl} \leftrightarrows \overset{+}{\mathrm{Na}} + \overset{-}{\mathrm{Cl}},$$

we would have

$$K_1pq = K_2r,$$

where p represents the concentration of the ion $\overset{+}{\mathrm{Na}}$, q that of the ion $\overset{-}{\mathrm{Cl}}$, and r that of the undissociated salt NaCl. From which

$$\frac{pq}{r} = \frac{K_2}{K_1} = K, \tag{2}$$

which is known as the dissociation or ionization constant, and is a constant for constant pressure and temperature, but is different for different salts.

For those acids and bases and their salts which are usually characterized as strong, K is found to be large, while on the contrary it is always small for the so-called weak acids, bases, and their salts. Since it is obvious that it is the active masses of the ions which make an acid or base weak or strong, the magnitude of K is generally taken as the measure of the relative "strength" of an acid or base at the present time.

Still applying formula (2) to such a case as

$$\mathrm{NaCl} \rightleftarrows \overset{+}{\mathrm{Na}} + \overset{-}{\mathrm{Cl}},$$

we see that for every $\overset{+}{\mathrm{Na}}$ ion there will be a $\overset{-}{\mathrm{Cl}}$ ion—that is, the concentration or active mass will be the same, and

$$\frac{p_2}{r} = K \text{ or } p_2 = Kr,$$

therefore the concentration of the undissociated salt is proportional to the square of the concentration of the dissociated salt. From which it follows that the greater the dilution the greater the proportion of dissociated to undissociated salt.

So far we have considered only cases of homogeneous equilibria where we had but one reversible reaction and complete solution. But there are certain types of heterogeneous equilibria which remain to be considered.

Suppose a solid salt, S, in contact with a solution saturated with respect to it. The salt which has gone into solution is partially dissociated into the ions A and B. In this case we are dealing with two equilibrium phenomena, the equilibrium between the solid salt and the undissociated salt in solution, and the equilibrium between the undissociated salt in solution and the dissociated salt in solution. The latter equilibrium is expressed in the equation

$$\frac{ab}{c} = K,$$

where a and b are the concentrations of the ions, and c that of the undissociated salt. But, as there is solid salt present, the concentration of the undissociated salt is constant, and the above equation becomes

$$ab = K_s,$$

where K_s is known as the "solubility constant."

The effect of the addition of a salt to a saturated solution of another salt may be predicted from the above equation. Suppose that a salt which in solution yields a common ion be added; for instance, let us add potassium chloride, which yields ions $\overset{+}{K}$ and $\overset{-}{Cl}$, to a saturated solution of sodium chloride, which yields the ions $\overset{+}{Na}$ and $\overset{-}{Cl}$. There is a tendency to increase K_s for sodium chloride, for the concentration of one of the ions, $\overset{-}{Cl}$, has been increased. As the value K_s is constant, the concentration of the other ion (Na) in the solution must decrease, and this is effected by a precipitation of sodium chloride. Thus, the effect of the addition of a salt which yields a common ion is in general to decrease the solubility of the other salt.

Suppose, on the other hand, that to a solution containing an electrolyte another containing no common ion be added. As has been already illustrated, there will be at once the formation of all the combinations possible to the ions, and with the consequent taking away of the ions for this purpose there will be a lowering of the product of ionic concentration for each of the salts; that is, the solubility will be increased. This phenomenon is most strikingly illustrated in the case of those salts usually regarded as insoluble. For instance, gypsum, which is essentially the salt calcium sulphate containing some water, is sparingly soluble in water. But the addition of an electrolyte with no common ion, such as sodium chloride, will considerably increase the solubility of the gypsum. So far as is known the addition of any electrolyte with an uncommon ion always increases the solubility of gypsum, for moderate amounts of the salt added, and the addition of an electrolyte with a common ion, such as a calcium salt or a sulphate, except, perhaps, in the case of sulphuric acid, always depresses the solubility of gypsum for moderate amounts of the salt added.

Water is itself a very weak acid with a very low ionization constant, but it does dissociate to a very limited extent into hydrogen and hydroxyl ions, thus:

$$H_2O \rightleftarrows \overset{+}{H} + \overset{-}{OH}.$$

These dissociated ions from water will of course react with the ions of the dissolved electrolyte, thus:

$$NaCl + HOH \rightleftarrows NaOH + HCl,$$

but the ionization constants of the sodium hydrate and the hydrochloric acid are very large, while that of water is relatively very small indeed, so that the latter will be formed and precipitated as such nearly completely, and the total effect will be so small as to be incapable of detection by ordinary methods. This will be true for any electrolyte with high ionization constant, but with an electrolyte which ionizes to a small degree the effect becomes important. Sodium carbonate has a very low ionization constant in water. The reaction is indicated thus:

$$Na_2CO_3 + HOH \rightleftarrows NaOH + HNaCO_3,$$

and while the acid sodium carbonate does dissociate further it is to a very slight extent, as is the dissociation of the sodium carbonate and water as compared with the dissociation or ionization of the sodium hydrate; in consequence, the solution behaves as though it were, as in fact it is, a solution of sodium hydroxide. This phenomenon of the dissociation of the salt of a weak acid or a weak base in water, with the formation of the corresponding strong base or acid possible, has been called *hydrolysis*. The ionization of water is increased by heating, a fact of importance in many analytical operations. It can be very beautifully illustrated with calcium carbonate. If powdered marble be shaken up with water it dissolves to a very slight extent and is hydrolized with the formation of calcium hydrate, which can be shown by the alkaline reaction with a few drops of phenolphthalein. On heating the color becomes very greatly intensified, but on cooling it gradually returns to its former condition. This increased hydrolytic power of heated waters is obviously of the first importance in studying geological problems involving the solution of such weak salts as carbonates, silicates, aluminates, and borates.

CLASSIFICATION OF ALKALI SOILS.

The various salts composing the alkali vary greatly in solubility. The more soluble salts will naturally go into solution more readily and rapidly than the less soluble ones. It will be convenient to consider the various phases of alkali presented to our attention as the results of the action of aqueous solutions of certain soluble salts upon less soluble salts.

Alkali has been conveniently classified as white and black, and this classification has been a very useful one in the past and is yet in some ways a convenient one, although it is often very unsatisfactory. For many purposes a classification based more specifically upon the chemical characteristics of the alkali or system of salts present would be preferable. That such classification can readily be made it is hoped will become evident as this paper proceeds.

PECOS TYPE.

From a general inspection of the analyses of the water-soluble constituents of the soils and crusts of the alkali areas, together with a study of the conditions in the field, it would appear that the nature of the alkali in any particular area has predominating features which may be considered as characterizing and differentiating it from other alkalies. In the Pecos Valley, New Mexico, it has been made very evident that the predominating feature is the contact of waters carrying considerable quantities of sodium chloride with the gypsum found abundantly in the soil, the gypsum, in fact, being in some places the main component of the soil. The sodium chloride, being so much more soluble, will be taken up long before the gypsum is appreciably affected, and we are therefore justified in regarding this problem as the action of aqueous solutions of sodium chloride upon gypsum ($CaSO_4 . 2H_2O$) or the dihydrate of calcium sulphate.

In aqueous solutions a reaction takes place between gypsum and sodium chloride, which may be represented thus,

$$CaSO_4 + NaCl \rightleftarrows Na_2SO_4 + CaCl_2,$$

part of the calcium and sulphions of the sparingly soluble calcium sulphate being converted into calcium chloride and sodium sulphate, compounds much more soluble than gypsum. If the solution were saturated with respect to gypsum by being kept in contact with this substance, more of the gypsum in the solid phase would go into solution to restore the equilibrium between the solid gypsum and its solution, which had been disturbed by the withdrawal of some of its component parts or ions to form sodium sulphate and calcium chloride. In other words, the gypsum becomes more soluble on account of the presence of sodium chloride and the solution more concentrated with respect to the total salts dissolved.

By the movement of the solution through the capillary spaces of the soil and the evaporation of the water at the surface the salts are brought toward the surface of the soil. If the solution becomes saturated before it reaches the surface, separation of solid salts will take place, but in any case the tendency will be toward the formation of a crust of the dissolved salts on the surface of the soil as they separate from solution on the evaporation of the water. The various salts on separating are more or less well crystallized, with the exception of the calcium chloride, which, on account of its great hydroscopiscity, is dehydrated only under extreme conditions and probably never separates in well-defined crystals in the field. It is evident that if water be added to the crust, the rate at which the several components will redissolve is dependent not only on their respective solubilities, but also very largely on their physical states, whether in large, well-defined crystals, exposing a relatively small surface to the solvent action of the water, or in a fine, pulverulent condition, thus exposing a very large surface to the action of the solution, etc. The calcium chloride would evidently go into solution more quickly than any other component of the crust. If the water were allowed to stand in contact with the crust for a sufficient length of time, all the salts would dissolve, to a greater or less extent, until a state of equilibrium was reached; but this is not what takes place when water is added, either by irrigation or by rain. It has been pointed out that the downward movement of such waters in the soil is quite rapid and is through the larger soil spaces, in contradistinction to the slow, upward movement of these waters through the capillary soil spaces; consequently on the addition of water to the soil or crust the calcium chloride, which goes into solution so much more rapidly than the other salts, is rapidly leached out and carried far down into the lower depths of the soil. When evaporation again sets in at the surface the calcium chloride, which has been carried so far below the other salts, either fails to reach the surface altogether or does so in lessened amounts. Thus it is that we practically never find calcium chloride and sodium sulphate in the crust in equivalent amounts, as we should expect a priori on the basis of the reaction between sodium chloride and calcium sulphate with the formation of some calcium chloride and an equivalent amount of sodium sulphates. Moreover, if the rate of movement of the different salts in the capillary spaces of the soil, after the salts have gone into solution, be different for different salts, it is incredible that the differences could be of such magnitude as to affect materially those features of the phenomena which have just been considered.

The calcium chloride which has been washed down into the subsoil accumulates there in certain places, and then on prolonged drought is sometimes brought to the surface in very large amounts in spots of limited area. On account of its well-known and very great property of deliquescence it keeps the surface where it has accumulated quite damp, even during periods of protracted drought. This gives a darker appearance to the soil where the calcium chloride has accumulated than that of the surrounding drier areas where this salt has not accumulated, these darkened areas being locally known in the Pecos Valley as black alkali spots, although chemical examination shows them to be quite free from soluble carbonates.

The metathesis or interaction of calcium sulphate and sodium chloride is the predominating feature of the alkali in the Pecos Valley. It is modified to some extent by the presence of other salts, as the salts of magnesium, for example; but the latter are always present in much smaller quantities than are the calcium and sodium salts. Soluble carbonates are almost entirely absent and merit no attention in this area. As the Pecos area was the first of the gypsum-sodium chloride type to receive extended investigation by this Bureau, it has been proposed to classify areas in which the interaction of gypsum and sodium chloride is the predominating feature under the heading "Pecos type."

FRESNO TYPE.

It has become evident that in the area about Fresno the prevailing feature of the alkali problem from the chemical point of view is the contact of aqueous solutions of sodium chloride with calcium carbonate. Large quantities of calcium carbonate are found in the soils of this area. Frequently it is the cementing material for more or less extensive beds of hardpan at various depths, usually a few feet below the surface and generally parallel to it. The sodium chloride in solution, on being brought into contact with calcium carbonate, reacts at once, as thus indicated:

$$CaCO_3 + NaCl \rightleftarrows Na_2CO_3 + CaCl_2$$

calcium chloride being formed as in the Pecos type, but sodium carbonate being the other constituent instead of sodium sulphate, as in the area last considered. The same general considerations apply here. The salts are brought to the surface by evaporation of the solvent and the movement of the solution through the capillary spaces of the soil. They are then, on the addition of water at the surface, partially dissolved and carried quickly down, the calcium chloride being more rapidly removed than the other salts during the process.

The study of this type presents some specially interesting phenomena. As has been pointed out elsewhere, the action between the calcium carbonate and the sodium chloride is much facilitated by the presence of carbon dioxide, this substance reacting with the calcium carbonate to form the much more soluble bicarbonate or hydrogen carbonate, and this latter substance then reacting with the sodium chloride. The reaction then would be expressed thus:

$$Ca(HCO_3)_2 + NaCl \rightleftarrows CaCl_2 + NaHCO_3.$$

The sodium hydrogen carbonate thus formed would be brought to the surface, and in much greater amounts than if the normal calcium carbonate had been its origin. On desiccation, the sodium hydrogen carbonate would be very largely inverted to the normal carbonate. In such areas the production of black alkali is notoriously great, for it is well known that soil grains have the power of condensing very considerable quantities of carbon dioxide, the soil thus containing much more of this agent than one would suppose from its very small partial pressure in the atmosphere above the soil, and wet or dry areas containing much organic matter are especially adapted to the formation and retention of carbon dioxide.

The presence of magnesium carbonate with the calcium carbonate, as is frequently the case in soils of this class, introduces some modifications as to degree in the formation of soluble carbonate; for magnesium carbonate is more soluble than calcium carbonate, and therefore its active mass would be greater. Therefore the contact of magnesium carbonate with sodium chloride would be expected to yield soluble carbonates more readily and in much greater amount than would the calcium carbonate alone. These views are fully substantiated by the investigation of certain alkali soils from California containing much lime-magnesium carbonate.

The occurrence of calcium chloride spots is quite common in this area. Usually there is also a small amount of soluble carbonates or bicarbonates present. When the calcium chloride is large in amount, the amount of soluble carbonate is quite small, and not infrequently disappears altogether; for calcium carbonate, being quite insoluble as compared with the other salts present, and likewise being but little dissociated, would be formed and precipitated as such. In such spots the application of water to the surface will first wash the excessive amount of calcium chloride away, and then the calcium carbonate will in turn react with the sodium chloride to re-form sodium carbonate. The formation of small amounts of black alkali may well be expected as one of the first results of irrigating such spots. With good drainage, however, the evil would be but a temporary one.

In areas of this type are occasionally found small deposits of nitrates. This is to be expected, for here the nitrifying organisms find calcium carbonate to neutralize the excess of nitric acid formed, and their functions are thus not interfered with and kept down to a low limit by an accumulation of their own product.

Since Fresno is the first area in which these relations have been carefully studied and in which they are not disguised to any considerable extent by the presence of other salts, it is proposed to designate alkali areas of the calcium carbonate-sodium chloride class as belonging to the Fresno type.

SALT LAKE TYPE.

The type of alkali most commonly met is one in which the conditions observed may be regarded as the result of the action of aqueous solutions of sodium chloride upon calcium carbonate (or calcium hydrogen carbonate) and gypsum simultaneously. By the action of the sodium chloride upon the calcium carbonate some sodium carbonate would be formed, and also an equivalent amount of calcium chloride. By the action of the sodium chloride upon the gypsum sodium sulphate would be formed, and again an equivalent amount of calcium chloride. This second reaction would take place in the direction of the formation of calcium chloride to a greater extent than the first, for the sulphates are stronger electrolytes than the carbonates, and, moreover, the solubility of the gypsum is probably in most cases greater than the solubility of the lime carbonate, even though there be much carbon dioxide present. The formation of the common product, calcium chloride, would tend to retard both reactions in the direction of the formation of this substance, but more the one involving the calcium carbonate. The formation of the corresponding sodium carbonate is therefore very much lessened by the presence of the gypsum, a fact which has long been known empirically and which has been sometimes employed in the amelioration of the conditions in land containing black alkali by the addition of gypsum, or land plaster. The reaction between the gypsum and the calcium carbonate would simply result in lowering the solubility of both salts, because they yield a common ion, but the effect would be much more marked in the case of the carbonate, both on account of its being a weak electrolyte and of its lesser solubility. Therefore the amount of the lime carbonate in the solution, or its "active mass," is much lessened, with a corresponding lessening of the extent to which it can react with the sodium chloride to form sodium carbonate.

It must be remembered that the rôle of carbon dioxide is probably of great importance in this connection. The amount of this substance in the soil atmosphere may be quite large, and in consequence the solubility of the lime carbonate may be considerably increased by the formation of the hydrogen carbonate. This might well increase somewhat the amount of sodium carbonate formed and at the same time lessen to some slight extent the formation of sodium sulphate. This is a matter of great importance, for it indicates that in this mixed type of alkali some soluble carbonates are to be expected, although the amount will be small and may usually be neglected in an economic consideration of the area involved; but in the case of the application of gypsum for the correction of black alkali, the relative proportion of gypsum applied to the salts already present is small. It may be expected to fulfill its rôle temporarily by acting on the soluble carbonates in immediate contact with it; but an increase of the soluble carbonates by more of this material coming to the surface from lower depths or by its formation from an increased solubility of the lime carbonate through an increase in the carbon dioxide dissolved in the ground solutions will require further additions of land plaster. Therefore this method of ameliorating black alkali can be regarded as but a temporary expedient, and has the further disadvantage that the action of the sodium chloride upon the gypsum results in an increase of the soluble salts in the soil. On the other hand, the presence of a large proportion of soluble lime salts has the apparent effect of enabling plants to withstand much larger quantities of other salts than would be possible in the absence of calcium from the soil solutions.

The characteristics of this type of alkali are, then, the presence of soluble chlorides, sulphates, and the relatively small but varying amounts of soluble carbonates. The first area containing this type of alkali that received detailed attention from this Bureau was in the Salt Lake Valley, Utah. The type is therefore tentatively designated as the Salt Lake type.

MODIFIED TYPES.

At Tempe, Ariz., it appears that the original conditions are very similar to those at Fresno, Cal., in that the principal reaction involved is the one between sodium chloride and calcium carbonate. But the investigations of Professor Forbes, of the Arizona Experiment Station, and of Mr. Means, formerly of this Bureau, have shown that considerable amounts of soluble sulphates are constantly being added to the soils through the application of irrigating waters carrying rather large amounts of these substances in solution. The result is gradually to modify the original type of alkali, making it more nearly resemble the Salt Lake type, although the amount of lime sulphate formed in the soil is hardly sufficient to justify a reclassification under this latter heading. The area is rather to be regarded for the present as a modification of the Fresno type.

In the virgin soils of this area, or in those very recently brought under irrigation, the formation of soluble carbonates has frequently been noticed; but in those soils which have been irrigated for some time with the sulphate-carrying waters the occurrence of soluble carbonates in more than traces, or practically negligible amounts, has been found to be unusual. These observations are entirely in accord with the ideas developed above.

In the valley of the Sevier River, Utah, the alkali areas are of unusual interest, the alkali being essentially of the Fresno type. The soils are uniformly underlain by sandy formations, giving good natural underdrainage, and hardpan areas are, therefore, unusual. Even in the virgin soils the amounts of alkali are never very large, and in the irrigated areas, as might be expected with good underdrainage, the amounts of alkali are considerably diminished.

It has been found by Mr. Gardner, of this Bureau, that in the virgin soils of this area there are considerable amounts of soluble normal carbonates, but as the total amounts of soluble salts decrease in the soils the carbonates decrease also, the proportion of hydrogen carbonates to normal carbonates greatly increasing. This is in entire accord with the laboratory observations of Cameron and Briggs[a] on the equilibrium between carbonates and bicarbonates in aqueous solution. It was found that seepage waters fresh from these soils contained, as a rule, no normal carbonates, although always containing some hydrogen carbonates. If these waters be allowed to stand in contact with air for a while, either in pools or by running in the river courses or canals, so that they more nearly approach equilibrium with the air, there is always a partial inversion of the hydrogen carbonate to normal carbonates, as evidenced by the reaction of the solutions toward phenolphthalein.

These observations have an important bearing on alkali studies, as they show most clearly that not only is underdrainage of great importance in diminishing the actual amount of alkali in the soil, but that where there is black alkali this much dreaded substance is at the same time very largely changed to the much less noxious hydrogen carbonate. The change becomes the more nearly complete as the total amount of soluble material decreases.

BILLINGS TYPE.

In the valley of the Yellowstone, in Montana, a distinctly different type of alkali is found.[b] There the alkali consists almost entirely of sulphates, only traces of chlorides being found. While soluble carbonates occur, as has been amply demonstrated in the laboratory of this Bureau by examinations of crusts collected near Billings, they are always in very small amounts, which can practically be disregarded in a consideration of the problems presented by this area. Crystals of gypsum are abundant in the Yellowstone soils and in the rocks from which these soils are formed. Occasionally the gypsum is associated with relatively small calcium carbonate deposits. Sodium or magnesium sulphate, the most common of the soluble salts of this area, would decrease the solubility of gypsum because they furnish a common ion in the SO_4 group. They would react to some extent with calcium carbonate, making it more soluble, according to the following scheme:

$$Na_2SO_4 + CaCO_3 \rightleftarrows Na_2CO_3 + CaSO_4.$$

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[a] Bul. 18, Division of Soils, U. S. Dept. Agr., 1901.

[b] The Alkali Soils of the Yellowstone Valley. By Milton Whitney and Thomas H. Means, Bul. 14, Division of Soils, U. S. Dept. Agr., 1898.

From the well-known properties of the individual salts it could be prophesied, what is actually found to be the case, that equilibrium in this system is reached when the reaction is mainly from right to left. In other words, the solubility of calcium carbonate is but slightly increased in the presence of sodium sulphate. In the presence of carbon dioxide, and the consequent formation of calcium bicarbonate or hydrogen carbonate, the reaction is much further displaced to the right, as indicated by the above scheme. On desiccation at the surface the sodium hydrogen carbonate would mainly invert to the form of the normal carbonate, and in the presence of so much gypsum and magnesium sulphate as is always present in these soils it would be quite rapidly converted to the slightly soluble alkaline earth carbonates and sodium sulphate.

Practically the only salt to be considered in this area is sodium sulphate and possibly in some cases magnesium sulphate. It would appear that the Fort Benton shales, from which a large portion of the soils of this valley are derived, contain considerable quantities of sulphide of iron as marcasite or pyrites. On weathering this material is superficially oxidized to the very soluble ferrous sulphate. By further oxidation and hydrolysis the major part of the iron is precipitated as the very slightly soluble ferric hydrate, this substance then becoming more or less mixed with carbonate of iron by absorption of carbon dioxide. Hydrated carbonate of iron has been identified in some of the samples from this locality now in the collection of the Bureau. At the same time that the ferric hydrate was precipitated free sulphuric acid must have been formed. This acid was quickly neutralized by its action upon the other mineral components of the soil, especially lime carbonate. It would seem probable that this process is in large part responsible for the sulphates so abundant here.

ALKALI IN HUMID REGIONS.

There are several cases on record where alkali salts have been found in the soils of humid regions in such proportions as to kill vegetation during dry weather. Such alkali patches have been observed in one of the fields of the Maryland Experiment Station at College Park, Md. Samples taken from the surface of the soil to a depth of one-eighth of an inch on analysis showed 1.83 per cent of water soluble solids, mainly the nitrates of calcium, magnesium, sodium, and potassium, together with some of the chlorides and sulphates. The analysis of a crust from the surface of a soil near Starke, Bradford County, Fla., showed 0.19 per cent water-soluble salts, mainly sodium chloride, but in part sulphate and phosphate. Both these samples were found on a compact smooth surface, from which evaporation was much more rapid than from the surface of the surrounding soils. The accumulation of water-soluble salts at the surface of the soils (after long-continued dry spells) has also been reported near Cumberland, Md., near Durant, Miss., near Houston, Tex., and at a number of other places in humid areas.

RELATIONS BETWEEN ALKALI AND VEGETATION.

In a paper on Some Mutual Relations between Alkali Soils and Vegetation,[a] Kearney and Cameron have investigated the effect upon seedling plants of certain components of the alkali salts. The plants which they selected for experiment were the white lupine (*Lupinus albus*) and alfalfa (*Medicago sativa*). They have determined for each of the salts the limit of concentration in which the root tips of young seedlings of white lupine could just survive, as follows:

Concentrations in which seedling roots can just survive.

Name of salt.	Concentration, parts per 100,000 of solution.	Name of salt.	Concentration, parts per 100,000 of solution.
Magnesium sulphate	7	Sodium chloride	116
Magnesium chloride	12	Sodium bicarbonate	117
Sodium carbonate	26	Calcium chloride	1,377
Sodium sulphate	53		

Experiments were made to ascertain the limit of endurance of seedlings of alfalfa, and although the absolute limits were not determined they appear to be lower for every salt than in the case of white lupine. Thus for magnesium sulphate the limit appears to be between 0.0006 and 0.0012 normal, while for magnesium chloride the limit is between 0.0012 and 0.0025 normal. From these results the conclusion is drawn that it is the basic radical rather than the acid radical of the salt which chiefly determines their relative toxicity.

In other words, the cations derived from these salts are very much more active in their effect upon plant tissues than are the anions. This is strikingly brought out by a comparison among themselves of the three chlorides of magnesium, sodium, and calcium, on the one hand, and of the chlorides and sulphates of magnesium and sodium, respectively, on the other. In the former case, although the anions (Cl) are identical in kind, we find magnesium chloride eight times as toxic as sodium chloride and one hundred times as toxic as calcium chloride. In the latter case, magnesium sulphate is only twice as toxic as magnesium chloride, while sodium sulphate is little more than two and one-half times as injurious as the corresponding chloride.

A comparison of the seven salts above enumerated in regard to the degree of concentration of each in which absolutely no elongation of the roots occurred during twenty-four hours is interesting, as illustrating how far this point is removed from that of the minimum concentration which is still toxic. It will be seen that the position of the salts in this scale does not at all correspond with their sequence in the table of limits of endurance. In many cases, especially when the solution was still more concentrated, not only no increase of length but a positive shrinkage of 0.5 to 2 mm. was detected.

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[a] Report No. 71, U. S. Dept. Agr. (1902).

Concentration of solutions in which no growth in roots took place in a period of twenty-four hours.

Name of salt.	Concentration, parts per 100,000 of solution.	Name of salt.	Concentration, parts per 100,000 of solution.
Sodium carbonate	260	Sodium sulphate	1,410
Sodium bicarbonate	417	Calcium chloride	1,652
Magnesium chloride	960	Magnesium sulphate	1,680
Sodium chloride	1,160		

It is impossible to reconcile this sequence, as compared with that of the table on page 158, with the notion that the injurious effect of these salt solutions is merely a function of their osmotic pressures. If any fresh evidence were needed to disprove this assumption it is afforded by the fact, very clearly brought out in the present investigations, that marked toxic effects frequently appear long before loss of turgor has manifested itself or cessation of growth has occurred. It is certain that no useful conclusions as to the degree of toxicity of a solution can be drawn from its osmotic pressure.

Besides the above easily soluble salts a few others were experimented upon—the sulphate of lime and the carbonate of lime and magnesia. In solutions in which these were present, gypsum in excess and calcium carbonate in excess, the plants grew decidedly more vigorously than in pure water. With a solution of calcium carbonate in saturated solution of carbon dioxide the roots grew only one-third as fast as in distilled water. Magnesium carbonate, which in solution gave a strong alkaline reaction with phenolphthalein, allowed the roots to grow about as rapidly as in distilled water, but when carbon dioxide was added in excess to this solution, which gave now no alkaline reaction, the roots made no growth during twenty-four hours.

Pure solutions of the salts dealt with are shown to be generally injurious to plants, and this largely by virtue of the cations which they yield, as a comparison of the position of the several salts in the table of toxicity in pure solutions shows conclusively. Thus magnesium salts, irrespective of the character of their anions, are much more injurious than is any sodium salt, while the three chlorides (of magnesium, sodium, and calcium) differ enormously in toxicity, regardless of the fact that they yield a common anion.

Upon comparing the limits of endurance for lupine roots in pure solutions of the "alkali" salts with the limits determined by the methods employed in a field survey, it became obvious that the former were vastly lower than the latter; and that furthermore the order of toxicity of the several salts as fixed by investigators in the field differed greatly from that obtained by experiments in the laboratory. This was strikingly the case with magnesium sulphate, which is decidedly the most toxic of the seven salts when alone in a pure aqueous solution, but which is regarded as the least injurious by students of alkali soils. But it was recalled that none of these salts usually occurs in any notable quantity in the soil save in the presence of one or several others, both of the readily soluble salts and of the comparatively insoluble magnesium carbonate, calcium carbonate, and calcium sulphate. The key to the discrepancy appeared therefore to lie in mixtures of the various salts, and the study of these became logically the next step in the investigation.

The following table shows the results of experiments with Lupinus in solutions of magnesium sulphate with other salts added:

Limits for magnesium sulphate in mixtures.

Name of salt added.	Greatest endurable concentration of magnesium sulphate.		Concentration of the salts added.	
	In fractions of a normal solution.	In parts per 100,000 of solution.	In fractions of a normal solution.	In parts per 100,000 of solution.
None	0.00125	7		
Magnesium chloride	.000625	3.5	0.0025	12
Sodium carbonate	.00125	7	.0025	13
Sodium sulphate	.00375	21	.01	80
Sodium chloride	.0075	42	.015	87
Calcium chloride	.2	1,120	.2	1,101
Magnesium carbonate	.01	56	Saturated.	Saturated.
Calcium carbonate	.02	112	Saturated.	Saturated.
Calcium sulphate	.6	3,360	Saturated.	Saturated.
Calcium sulphate and calcium carbonate	.4	2,240	Saturated.	Saturated.

In the light of figures given above, the enormous discrepancy between the results obtained by experiments with this salt in pure solution and the limit determined by field survey is completely obliterated. For in alkali lands magnesium sulphate is rarely, if ever, found in any quantity except in the presence of calcium sulphate; and it is commonly accompanied by both sodium and calcium sulphate (the Billings, Mont., type of alkali soil). Addition of sodium sulphate, which is itself so injurious in a pure solution, raises the limit for magnesium sulphate three times, while the presence of calcium sulphate allows a small proportion of the roots to barely survive during twenty-four hours in a solution of magnesium sulphate 480 times as concentrated as that which, in pure solution, represents the limit of endurance. A careful comparison was made between 0.3 and 0.4 normal solutions of magnesium sulphate, both in the absence and the presence of an excess of calcium sulphate, five individuals of *Lupinus albus* being cultivated for forty-eight hours in each of the four solutions.

The following table gives the results:

Magnesium sulphate with and without calcium sulphate.

Solutions.	Average elongation of the marked portion of the root.	General condition of the roots.
	Millimeters.	
Magnesium sulphate (0.3 normal)	0.7	Extremely flaccid and discolored with brownish blotches; extremely plasmolyzed.
Magnesium sulphate (0.3 normal) + calcium sulphate.	10.2	Turgor normal; plasmolysis none; but all roots quite badly discolored.
Magnesium sulphate (0.4 normal)	.3	About as in 0.3 normal
Magnesium sulphate (0.4 normal) + calcium sulphate.	13.0	Turgor normal; plasmolysis none; all but one root quite badly discolored.

The superior efficacy of cations over anions in neutralizing the toxic effect of other cations is illustrated by the discovery that sodium is equally effective as an antidote to magnesium chloride, whether it be added as sulphate (Na_2SO_4) or as chloride (NaCl).[a] A much more striking illustration is afforded by the fact that calcium, when added to a solution of magnesium sulphate or of sodium sulphate, is very much more efficacious when furnished as the relatively insoluble sulphate than as the readily soluble chloride. In other words, the presence of chlorine anions actually hinders the full exertion of the physiological effect of calcium cations, unless we are to believe that the superior efficacy of calcium sulphate is due merely to its greater influence in retarding the dissociation of the sulphates of magnesium and of sodium.

If we turn now to the effect of mixtures in which two kinds of cations are present we find that these are almost invariably much less poisonous than is the pure solution of the more toxic salt. Even the addition of a sodium salt (sulphate or chloride) to one of magnesium (sulphate or chloride) raises the limit of endurance for the latter three to six times. Still more remarkable is the effect of magnesium carbonate as an antidote to salts of sodium (carbonate, sulphate, chloride), raising their limits two to four times. But these effects are trivial as compared with the extraordinary efficacy of calcium in counteracting the toxic effects of other bases (magnesium, sodium).

Even when added as the but slightly soluble carbonate, calcium raises the limit of magnesium sulphate and of magnesium chloride sixteen times, of sodium sulphate more than five times, and of sodium chloride three times. Calcium chloride mixed with an equal volume of a magnesium or a sodium salt raises the limit of the latter as follows: Magnesium sulphate, one hundred and sixty times; magnesium chloride, forty times; sodium carbonate, fifty times; sodium sulphate, twenty-seven times, and sodium chloride, ten times.

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[a] On the other hand, sodium chloride is twice as effective as sodium sulphate in neutralizing magnesium sulphate.

The most effective of the calcium salts tried was, however, calcium sulphate. This, when added alone in solid excess, increases the maxima of concentration endurable by the roots as follows: Magnesium sulphate, four hundred and eighty times; magnesium chloride, eighty times; sodium carbonate, six times; sodium sulphate, sixty-six times, and sodium chloride, ten times.

Similar results have been obtained for magnesium chloride, sodium carbonate, sodium sulphate, sodium chloride, and calcium chloride in mixture.

It was further demonstrated by Kearney and Cameron that in the case of certain salts, when plant roots are exposed to pure solutions which are much too dilute to produce any toxic effect, there occurred a decidedly stimulating effect upon growth, as compared with that in the distilled-water control during a corresponding period. As would be expected, this was shown to be the case for salts of calcium, both the chloride and the sulphate acting as stimuli. Here, however, we have to do with salts which contain valuable elements of plant food.

But a marked stimulating action occurs in pure solutions of sodium carbonate (slight in 0.002 normal, marked in 0.00125 normal, and of sodium bicarbonate 0.01 normal). The most pronounced effect was obtained in a 0.00125 normal solution of sodium carbonate, the average elongation of the roots in that solution being one and one-half times as great as in distilled water during the same period. In the case of the two carbonates of sodium it seems necessary to regard the effect as one of chemical stimulus, pure and simple. That this is not due to the sodium ions is evident from the fact that very dilute solutions of other sodium salts (sulphate, chloride) gave purely negative results. It was at first thought that the physiological effects of sodium carbonate (Na_2CO_3) were attributable to the presence of hydroxyl ions in the solution, since the corrosive, clearing action of more concentrated solutions of this salt is precisely similar to that produced by potassium hydrate and sodium hydrate. But toxic as well as stimulating reactions of exactly the same character were obtained with solutions of the bicarbonate ($NaHCO_3$), in which a large excess of carbon dioxide was dissolved, and which gave no reaction with phenolphthalein, even at the end of the experiment.[a] In this case the consideration of free hydroxyl ions must be excluded. Hence the conclusion seems unavoidable that the carbonic acid (HCO_3) ions produce the stimulating effect, improbable as this would appear. To what agency should be ascribed the characteristic toxic action (so different in kind from that of sodium sulphate and sodium chloride) of stronger solutions of sodium bicarbonate, in which no free hydroxyl could be detected, is a question to which no answer can at present be given.[a]

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[a] Solutions of sodium carbonate which were many times too dilute to produce a stimulating effect, yet gave a strong reaction with phenolphthalein.

None of the other salts with which experiments were made in pure solution were shown to stimulate elongation of the roots, although the possibility is not excluded that solutions still more dilute than those employed will give positive results. Magnesium sulphate was found to be indifferent (neither toxic nor stimulating) at 0.0003125 normal, magnesium chloride at 0.000625 normal, sodium sulphate (nearly) at 0.002 normal, and sodium chloride[b] (approximately) at 0.005 normal.

These observations accord with the well-known principle that many violent poisons, if given in sufficiently minute doses, serve as beneficial stimuli. Familiar examples are the action of arsenic, mercury, strychnine, digitaline, etc., upon animals. Numerous investigators have obtained similar effects with plants by supplying them with very small quantities of various substances which can not be regarded as sources of plant food, such as the extremely toxic salts of some of the heavy metals. In practically all such cases, however, it is very probable that considerable hydrolysis had taken place and that the stimulation might well be attributed to the hydroxyl ions thus introduced into the solution.

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[a] In experiments with sodium carbonate and sodium bicarbonate as to their effect upon animals, Loeb encountered a very similar anomaly. The stimulating effect of various hydrates upon the absorption of water by a muscle immersed in a sodium chloride solution was shown to be clearly due to the hydroxyl ions, being equal in amount when equivalent solutions of hydrates were used, irrespective of the character of the basic ions [see Pflüger's Archiv, 69, 10 (1898)]. The similar effect produced by carbonates of sodium and potassium was ascribed to the same factor, the hydroxyl ions (l. c., p. 20). On the other hand, the effect of sodium carbonate (Na_2CO_3) in stimulating skeleton formation in the pluteus of a sea urchin appears to be due to the carbonic acid (HCO_3) ions, since sodium in other forms, as well as hydroxyl in the form of potassium hydrate, gave negative results [Am. Journ. Physiology, 443 (1900)].

[b] Pfeffer [Pflanzenphysiologie, ed. 2, 1, 425] observes that possibly chlorides (e. g., sodium chloride), like so many other substances, act in dilute solutions as chemical stimuli. Storp [Biedermann's Centralbl., 13, 76 (1884)] obtained a stimulating effect upon the germination of seeds by immersing them in a 0.01 per cent solution of sodium chloride. Jarius [Landw. Vers.-Stat., **32**, 149 (1886)] found that even a 0.4 per cent solution of sodium chloride stimulated the germination of seeds of wheat, rye, rape, maize, beans, and vetches. Jones and Orton (Bul. Vermont Agr. Exp. Station No. 56, p. 12) observed, as a consequence of the application of sodium chloride to land in order to exterminate the weed known as orange hawkweed (*Hieracium aurantiacum*), a marked stimulating effect upon the growth of grass in the same field. Peligot [Comptes rendus, **73**, 1078 (1871)] suggests that the stimulating effect upon field crops which is sometimes obtained with sodium chloride may be due to its facilitating the decomposition of calcium phosphate and thus increasing the amount of phosphoric acid at the disposal of the plant. Kellner [Landw. Vers.-Stat., **32**, 365 (1886)] attributes to a similar liberation of phosphoric acid the stimulating effects of iron sulphate upon plant growth recorded by Koenig and by Griffiths. Réveil [De l'action des poisons sur les plantes, p. 41 (1865)] found that sodium hypochlorite in a solution of 0.1 per cent stimulates germination and growth, but is injurious, especially to herbaceous plants, when applied in greater concentration.

The effect of acids and of salts upon the seedlings of Indian corn (*Zea mais*), wheat (*Triticum vulgaris*), and clover (*Trifolium pratense*) have been investigated by Cameron and Breazeale.[a] The following table gives the toxic limits for seedlings in acid solutions:

Toxic limits for seedlings in acid solutions.

Solution.	Number of liters per gram at toxic limits for—		
	Corn.	Wheat.	Clover.
Hydrogen sulphate	3,000	15,000	20,000
Hydrogen chloride	3,000	18,000	20,000
Hydrogen nitrate	2,250	15,000	20,000
Hydrogen acetate	850	20,000	20,000
Hydrogen oxalate	1,750	15,000	20,000
Hydrogen succinate	600	20,000	20,000
Hydrogen malate	1,250	20,000	20,000

In the case of clover the uniformity of the figures for the limits in acid solutions is striking and seems to indicate that the toxic action was due to the hydrogen ion alone, for it must be assumed that with a dilution N/20,000 practically complete dissociation exists for each and every one of the acids. But the results obtained with wheat seedlings are not in accord with this view, since the dilutions were also such as to insure complete dissociation, although quite different concentrations of the several acids gave the toxic limits. With the corn seedlings in acid solutions the results are quite as difficult to interpret. They can not be regarded as due to this effect of the hydrogen ion alone, as the concentration with respect to this substance in the solutions representing the toxic limits varies considerably.

In the following tables are given results obtained in solutions of acids when in addition to the free acid H the indicated amounts of a corresponding potassium or calcium salt, respectively, were also present:

Toxic limits for seedlings in solutions of acids containing various amounts of the corresponding potassium salts.

Plant.	Solution.	Number of liters per gram at toxic limits with respect to free acid in solutions containing—		
		No potassium.	N/100 potassium.	N/50 potassium.
Corn	Sulphuric acid	3,000	2,100	1,750
	Hydrochloric acid	3,000	2,500	1,750
	Nitric acid	2,250	2,100	1,750
	Acetic acid	850	700	500
	Oxalic acid	1,750	1,000	800
	Succinic acid	600	75	60
	Malic acid	1,250	750	125
Wheat	Sulphuric acid	15,000	8,000	7,000
	Hydrochloric acid	18,000	8,250	7,250
	Nitric acid	15,000	7,750	7,000

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[a] Jour. Phys. Chem., 8, 1 (1904).

Toxic limits for seedlings in solutions of acids containing various amounts of corresponding calcium salts.

Plant.	Solution.	Number of liters per gram at toxic limits with respect to free acid in solutions containing—			
		No calcium.	N/100 calcium.	N/50 calcium.	Saturated with calcium.
Corn	Sulphuric acid	3,000	950	700	400
	Hydrochloric acid	3,000	1,750	1,200	....
	Nitric acid	2,250	1,500	1,000	....
	Acetic acid	850	500	400	....
	Oxalic acid	1,750	....	....	1,500
	Succinic acid	600	35	20	10
	Malic acid	1,250	200	100	100
Wheat	Sulphuric acid	15,000	5,250	2,250	....
	Hydrochloric acid	18,000	3,250	2,750	....
	Nitric acid	15,000	3,000	2,000	....
Clover	Sulphuric acid	20,000	3,250	1,750	1,700
	Hydrochloric acid	20,000	4,000	2,750	....
	Nitric acid	20,000	3,500	1,750	....
	Oxalic acid	20,000	....	....	15,000

In a recent paper,[a] Breazeale has determined the concentration of a nutrient solution which is best adapted to the growth of wheat. The nutrient solution contained chemically equivalent amounts of calcium sulphate, magnesium phosphate, potassium carbonate, sodium nitrate, and ammonium chloride. To solutions containing 10, 70, 150, 745, and 1,545 parts per million, respectively, ferric chloride was added in such quantity as to give a solution containing 5 parts per million of this salt. After fifteen days the average transpiration of over 200 plants was as follows:

Average transpiration of 200 wheat plants growing in solutions of different concentrations.

Solution concentration.	Relative transpiration.
P. p. m.	
15	100
75	161.6
155	188.7
750	163.3
1,550	131.9

The concentration which gives the maximum in transpiration is about 300 parts per million of total solids. The effect of adding relatively large quantities of one of the constituents of the nutrient solution is given in the following table. The time of the experiment was thirteen days.

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[a] Science, N. S. **22**, 146 (1905).

Average transpiration of 60 wheat plants growing in solutions of different concentrations.

Medium.	Relative transpirations for period of experiment.
Nutrient solution, 15 parts per million	100.0
Same+140 parts per million $CaSO_4$	205.5
Same+140 parts per million $MgHPO_4$	143.5
Same+140 parts per million K_2CO_3	224.4
Same+140 parts per million $NaNO_3$	156.3
Same+140 parts per million of four above salts in chemical equivalent amounts	241.9
Nutrient solution 15 parts per million	100.0
Same+60 parts per million $CaSO_4$	117.8
Same+140 parts per million $CaSO_4$	157.7
Same+735 parts per million $CaSO_4$	188.9
Same+1,535 parts per million $CaSO_4$	155.5
Nutrient solution, 15 parts per million	100.0
Same+60 parts per million NaCl	111.1
Same+140 parts per million NaCl	114.9
Same+735 parts per million NaCl	117.2
Same+1,535 parts per million NaCl	95.4

Sodium chloride, which furnishes none of the elements usually classified as plant-food materials, was also used to increase the concentration of the original solution. Sixty plants were used in this case, being grown for fifteen days. The treatment was the same as that with calcium sulphate just described, and the results showed the same general effect, although the actual differences between the different cultures were not nearly as great. The last fact is probably due to the toxic effect of the chlorine ion, tending to retard growth and thus partially masking the effect of concentration.

RESISTANCE OF PLANTS TO BLACK ALKALI.

In a paper by Cameron upon the Resistance to Black Alkali by Certain Plants[a] it has been shown that certain plant species can make a satisfactory growth on soils containing relatively large amounts of soluble carbonates. The plants *Distichlis spicata*, *Suæda intermedia*, and *Atriplex bracteosa* have been shown to exude considerable amounts of soluble organic acids, which tend to reduce the alkalinity in the immediate neighborhood of the plant and especially about the root crowns, where corrosion by black alkali has been so frequently observed.

From all these experiments it is apparent that the toxicity of any salt in solution is greatly modified by the presence of other salts, and that the toxic effect is by no means the same as the toxic effect of the several constituents. For instance, a solution containing 7 parts per 100,000 of magnesium sulphate or a solution containing 53 parts per 100,000 of sodium sulphate will kill seedlings of white lupine. With a solution of the two salts, however, containing 21 parts of magnesium sulphate and 80 parts of sodium sulphate it is just toxic to these seedlings. Such cases might be multiplied. The effect of one kind of ion in counteracting the physiological action of another kind can not be entirely explained by a study of the chemistry of the solution itself, but must in part be referred to complicated changes in the protoplasm of the organisms. The theory that ions furnished by the dissociation of electrolytes form intimate combinations with the proteids of protoplasm, and that their mutually antagonistic effect expresses itself in a replacement of one kind of ion by another as a result of change in the composition of the surrounding solution, would appear to afford the key to this problem.

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[a] Report No. 71, U. S. Dept. Agr. (1902), p. 71.

FORMATION OF ALKALI BY PLANTS.

The great value of saltbushes for certain soil conditions and for certain kinds of cattle feeding seems to be well established, but there is an element of danger, expressed in the prevalent belief that most of these indigenous plants convert the less harmful neutral salts, such as sodium chloride and sodium sulphate, into alkali carbonates—that is to say, the less harmful "white alkali" is converted into the more noxious "black alkali," as has been shown by the presence of sodium carbonate immediately under such plants, whereas no trace of it exists some distance away. It may be possible that the plants with their enormous root systems actually gather up minute traces of sodium carbonate, which may be present in lower depths of soil, gradually causing an accumulation at the surface on the decay of their roots and branches. But the generally accepted hypothesis of the conversion of the neutral salts appears more probable.

A specimen of the creosote bush (*Covillea tridentata*) was examined. This, while a desert plant, is said to shun soils where there is much water-soluble salts, and that its presence can be taken as a sure indication of land free from injurious quantities of alkali. It is found in dry, well-drained upland soils.

The aqueous extract of the dried leaves failed to show the presence of any sodium carbonate or sodium chloride, although it was slightly acid. It would appear that the chlorine and sodium, which are found on analysis of the ash, are in organic combination and that the salts are formed in the process of ashing the plant. From an analysis of different parts of the plant Cameron[a] has found that the amount of chlorine in the leaves is nearly three times that found in the stems. Thus the chlorine present is probably being concentrated in the leaves and is in organic combination.

From the results of the analysis of greasewood (*Sarcobatus vermiculatus*), before and after ashing, it appears that the plant contains all its chlorine as soluble chlorides, while the carbonate of sodium, which composes over one-half of the ash of the leaves and blossoms, is formed in the process of ashing.

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[a] Report No. 71, U. S. Dept. Agr., p. 64.

A striking feature is the much larger amount of ash from the leaves and blossoms than from the stems and the markedly larger percentage of the alkali salts in the ash of the former. The idea suggests itself that possibly this plant takes up and stores the salts and holds them as such until it is ready to use such part of them as it needs. On the other hand, it may be that these salts are present only because the plants can not prevent their accumulation, and, so far from being an inherent feature of the plant's economy, it may be a most undesirable accident due to their peculiar environment, but an accident in spite of which these particular plants are able to survive. But, as Schimper[a] has pointed out, this can not be true in all cases, as evidenced by the fact that halophilous plants show a tendency to take up more salts than nonhalophilous species, even when grown in nonsaline soils.

It is evident that in the decay of wood or leaves or, in general, of plant tissues alkaline carbonates are furnished to the soil. It may be that the process of decay will furnish at the same time organic acids stronger than carbonic acid and in sufficient quantity to combine with all the bases and prevent an alkaline reaction. In humid regions the alkali thus formed is removed by leaching or similar processes and by chemical reactions with the other soil components, for which reactions water is necessary.

RECLAMATION OF ALKALI LANDS.

The first question naturally arising in considering the reclamation of alkali lands is: Are the lands productive after their reclamation has been accomplished? Of this there can be no question, since they are rendered unfit for cultivation only because of the excess of certain soluble salts they contain. It has long been pointed out that a slight quantity of these salts even stimulates crops, and it is only when they accumulate in large quantities that the lands cease to be of value for agricultural purposes. In countries of abundant rainfall the application of common salts upon the lands has been practiced perhaps for centuries. In southeastern Europe it is customary in some districts to scrape up the surface accumulations of alkali and apply them to lands where no such accumulations occur, and the expression is common that salt is the life of the soil. Moreover, there are many examples of the great productiveness of reclaimed alkali land, not only in the arid regions of the United States, but in India and northern Africa as well.

This leads, then, to the question: Is the reclamation of alkali lands practical—that is, does it pay to reclaim such lands? The cost of reclaiming alkali lands depends on many factors, and in considering any system of reclamation the value of the land after it has been reclaimed must be taken into account. In new and partially developed districts where excellent virgin soil can be purchased for a few dollars an acre it is obvious that it would not be feasible to expend much time or money on reclaiming alkali lands. So rapid has been the development in the West, however, that the localities where fine land can be purchased at such prices are fast becoming the rare exception. In by far the greater part of the irrigated West land values have advanced so rapidly that seldom are good lands to be had at less than from $30 to $50 an acre, while in the older and better developed regions good lands frequently find ready sale at several hundred dollars an acre. In many of the older irrigated districts, moreover, the acreage of good lands is limited, and with the fancy prices which good soils command the rancher can well turn his attention to the reclamation of alkali lands, though this may prove somewhat expensive. The extent of land damaged by alkali has already been mentioned as being, according to conservative estimates, one-tenth of the entire area of irrigated land in the western part of the United States, or 847,000 acres. When we realize that this area is yearly increasing, the importance of reclaiming such lands is strongly emphasized.

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[a] Schimper, Pflanzengeographie, p. 101 (1898).

METHODS USED IN RECLAIMING ALKALI LANDS.

Among the most prominent methods proposed for reclaiming alkali lands may be mentioned the removal of the crust by scraping, the application of chemical correctives, the growing of alkali-resistant crops, flooding and then drawing off the water, and repeated flooding combined with underdrainage.

SCRAPING THE SURFACE.

The removal of alkali salts by scraping the surface calls for much labor and must in most cases be constantly repeated, any good that may result being merely temporary. In case the greater part of the alkali has accumulated at the surface and the deep subsoil contains little or no alkali, permanent good may result from this method, since by the removal of the alkali from the surface crops may be grown, and by subsequent cultivation or by keeping the surface shaded evaporation and the attending accumulation of alkali may be reduced to a minimum. The cases where large surface accumulations of alkali occur with none in the subsoil are rare, however, and this method of reclamation probably has not a wide application.

APPLYING CHEMICAL CORRECTIVES.

The second method of treating lands has been widely advocated and practiced for many years, especially in California. In some cases permanent benefit results from this method of reclamation. It has been long emphasized that the application of gypsum to land containing black alkali (sodium carbonate) results in changing the extremely injurious black alkali to white alkali, which is not as harmful to plant growth. The following chemical reaction takes place:

$$Na_2CO_3 + CaSO_4 \rightleftarrows CaCO_3 + Na_2SO_4,$$

the sodium carbonate being to a greater or less extent converted to less harmful sodium sulphate and the harmless and but slightly soluble carbonate of lime. To bring about this result, it is necessary that the soil should be well drained and aerated. This method of treatment of black alkali was first suggested by Hilgard many years ago. To test the efficiency of this treatment, experiments were conducted on a piece of land near Tulare Lake on soil strongly impregnated with black alkali. For many years gypsum has been applied to the soil with varying degrees of success. Much of the land was benefited, but other parts of the tract did not respond as quickly as hoped for, and the land was still being treated as late as 1904.

In the Yearbook[a] for 1895 Hilgard speaks of the use of gypsum as follows:

> The amount required per acre will, of course, vary with the amount of salts in the soil, all the way from a few hundred pounds to several tons in the case of strong alkali spots; but it is not usually necessary to add the entire quantity at once, provided that sufficient be used to neutralize the alkali near the surface and enough time be allowed for the action to take place. In very wet soil this may occur within a few weeks; in merely damp soils, in the course of months; but usually the effect increases for years, as the salts rise from below.
>
> The effect of gypsum on black alkali land is often very striking, even to the eye. The blackish puddles and spots disappear, because the gypsum renders the dissolved humus insoluble and thus restores it to the soil. The latter soon loses its hard, puddled condition and crumbles and bulges into a loose mass into which water now soaks freely, bringing up the previously depressed spots to the general level of the land. On the surface thus changed seeds now germinate and grow without hindrance; and as the injury from alkali occurs at or near the surface, it is usually best to simply harrow in the plaster, leaving the water to carry it down in solution. It must not be forgotten that this beneficial change may go backward if the land thus treated is permitted to be swamped by irrigation water or otherwise.

On soils containing slight quantities of sodium carbonate with but small amounts of white alkali, this treatment is advisable, since the sodium sulphate resulting from the chemical reaction is one of the least harmful varieties of white alkali, and greater quantities of this material can be endured by growing crops. The gypsum is also of benefit in correcting the unfavorable physical condition caused by the black alkali and restoring the soil to a good condition of tilth. On soils containing any considerable quantities of sodium carbonate it is to be doubted if the application of gypsum is to be advised, since the treatment does not remove the alkali, but merely changes it to a less injurious form. Even after the chemical reaction has taken place there still may be present in the soil too much of the sulphate to grow crops with success. Again, it should be noted that this method does not remove the cause of the accumulation of the alkali, and it is frequently but a question of time until the white alkali itself will accumulate in sufficient quantities to be destructive of plant life. It should also be pointed out that this treatment is of no value on lands other than those carrying sodium carbonate. No chemical treatment can at present be recommended on lands containing either chlorides or sulphates, and as many districts contain the one or the other of these as the predominating salt, this method of reclamation is of limited application. The use of gypsum as a corrective of black alkali has never been strongly recommended by this Bureau, since it is believed that other methods of reclamation are more permanent, and, all conditions considered, are more economical.

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[a] Yearbook of the Department of Agriculture, 1895, Origin, Value, and Reclamation of Alkali Lands, E. W. Hilgard.

GROWING ALKALI-RESISTANT PLANTS.

Concerning the third method of reclaiming alkali lands much has been written by the various experiment stations in the Western States. The utilization of such lands and the gradual removal of the excess of alkali salts has been attempted with partial success by the growing of certain alkali-resisting plants of more or less economical value. The harvesting of the crop in the case of such plants removes a considerable amount of the alkali salts which have been taken into the plant tissues and cells. This method is successful only to a limited extent, and it likewise fails to remove the cause. For the strongest alkali soils the wild saltbushes, salt grass, and Australian saltbush are available. Such lands can only be used as pastures. Lands less strongly impregnated will frequently grow sorghum or sugar beets, which can withstand considerable alkali. The growth of such plants alone is a slow and uncertain method of reclamation, but under certain conditions this method may be used to derive some income from lands at present having little or no agricultural value.

FLOODING AND DRAWING OFF THE WATER.

In many districts it is a common practice to build small dikes around a field containing alkali. The field is then flooded, the water allowed to remain for a short time, and then the banks are cut and the water drawn off. The principle is to dissolve the surface coating of salt and flood it off. Jensen, in the report of the Yakima area in Washington, states that this method is practiced in the Atanum Valley. In speaking of the efficiency of the method, Jensen writes as follows:

> This is an excellent method for filling up the soil completely with alkaline water and for the accumulation of more alkali by evaporation. Not only is the subsoil water under the

particular area itself raised, but also under other lands lying below it. This is the very way the alkali in this area originated, and no better method could be devised for making the general conditions of the area worse than they already are. A series of such dikes and the surrounding soil seen in June (1901) resembled snowdrifts, the white material being heavy accumulations of alkaline carbonates.

As Hilgard years ago pointed out, the reason this method avails nothing is that at the first wetting of the soil the dissolved salts immediately sink into the soil, and the water standing on the soil remains almost unchanged. There are some cases, however, where this method may be productive of good results.

APPLICATION OF MANURE.

Another method of treating alkali land is the application of manure. In itself the manure has but little, if any, power to change the chemical composition of the alkali. It may, however, as Tinsley[a] suggests, be the means of putting the soil in better physical condition, so that it will permit irrigation water more readily to permeate it, thereby washing the alkali below the surface and permitting shallow-rooted crops to make a growth. It may also stimulate the growth and vigor of young plants, and in this manner enable them better to withstand the injurious effects of alkali. The general result from this method of treatment in most cases is negative and need receive no further consideration.

TREATMENT OF ALKALI SOILS IN EGYPT.

In Egypt the reclamation of alkali lands has received a great deal of attention for many years. In 1902 Means made a study of the alkali conditions and the different methods of reclamation in use. The following summary is taken from Bulletin 21 of this Bureau, in which Means described the results of his studies. He found three methods of reclamation in use, each of which was successful under the conditions appropriate for its use.

Colmatage or warping.—This method of reclamation consists simply in flooding land with muddy water long enough to allow the mud to settle, after which the clear water is drawn off and more muddy water run on. Very little attention is paid to drainage, except in so far as surface drains are dug to carry away the clear water. The popular impression prevails that by this method the alkali or salt is covered up with sufficient good soil to permit plant roots to thrive. As a matter of fact, the efficiency of the method depends much more on the fact that the alkali is washed down into and mixed with the subsoil, so that its concentration at the surface is diminished. The total amount of alkali in the soil is very slightly reduced, and when conditions again become favorable for the rise of the alkali it returns to the surface and proves as troublesome as before. Where, however, the depth of soil and subsoil above standing water is great, and where rice or other wet-land crops are to be grown, colmatage may advantageously be used for reclamation. Large quantities of water are required and much land is made swampy. As an efficient and permanent remedy for alkali land this method can not be recommended for general use.

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[a] Alkali. By J. D. Tinsley. Bul. No. 40, N. Mex. Expt. Sta.

Flooding with open drains.—This is the method in common use in Egypt. The land is thoroughly leveled, open ditches to a depth of 32 inches are dug at intervals of 150 to 450 feet, and the land is banked up and flooded to a depth of 4 inches until sufficiently leached of alkali or salt to permit plant growth. This method is thoroughly effective for the removal of salt, but it has the objectionable feature of open ditches.

Flooding with tile drains.—This method has only been tried experimentally in Egypt, but promises to be the most rapid and effective way of reclaiming the land. Tile drains are placed 30 inches deep and 35 feet apart, at a cost of $30 per acre.

FLOODING AND UNDERDRAINAGE.

In principle this method is exceedingly simple. The accumulations of alkali are easily soluble in water, and if sufficient water is applied to the surface it will soak through the soil and carry with it the dissolved alkali, thus freeing the soil from such harmful accumulations. Repeated flooding will eventually leach all of the alkali from the soil, provided the underdrainage permits the water to pass readily through the soil. It has long been the custom of the Pima Indians in the Salt River Valley, Arizona, to take up the alkali lands that were irrigated in prehistoric times. By diverting the water from the Salt River through small ditches they heavily flooded the lands, washing the alkali into the deep porous subsoil, where it drained away with the country drainage. In this manner the lands were sufficiently reclaimed to permit cultivation of even the most sensitive crops. This is perhaps the first known example of successful alkali reclamation in this country.

As a result of the detailed study of the soil and alkali condition in the various parts of the arid West, the Bureau soon was convinced of the feasibility of reclaiming alkali lands by flooding after some system of drainage had been installed. Notwithstanding the recommendations in the various reports of the areas studied that drainage is a practicable, safe, and sure means of permanently reclaiming alkali lands, no steps had been taken by persons most deeply interested to check or remove the evil. The Bureau, after careful consideration, decided that the most convincing way of bringing the truth of its recommendations and the value of drainage in reclamation work before the people was to demonstrate it by the actual reclamation of some of the alkali land.

RECLAMATION EXPERIMENTS CARRIED ON BY THE BUREAU OF SOILS.

SALT LAKE CITY TRACT, UTAH.

In the year 1902 a tract of 40 acres was selected west of Salt Lake City, Utah, and steps taken to reclaim the land. During the period of 1902–1904 the work was carried on under the direction of W. H. Heileman, assisted by Rudolph Boss. In the following pages the history of the reclamation work is given from 1902 to the close of the farming season of 1905. Circular No. 12, published in 1903 by this Bureau, discusses the installation of the drainage system. The following statements consist of excerpts from that circular, together with a discussion of the results accomplished since its publication.

In 1899 a party from the Bureau of Soils, in cooperation with the Utah Experiment Station, made a soil survey[a] of that portion of the Salt Lake Valley lying west of the Jordan River. In this report full and careful consideration was given to the question of the alkali soils around Salt Lake City, the cause of their formation, their character and present extent, and the means of their amelioration and reclamation. The following paragraphs are taken from this report:

> On the west side of the Jordan River the earliest attempts at irrigation were on the Jordan meadows, or river bottom lands, the water supply being obtained from the Jordan River by means of small canals. Subsequently the Brighton and North Point and the North Jordan canals were run upon the first terrace above the river, and following these were the South Jordan and the Utah and Salt Lake canals on the second and third benches, respectively.
>
> As is frequently the case, the irrigation on the benches caused an accumulation of seepage and alkali on the river bottom land, so that much of it has been abandoned. The largest and most seriously damaged area, however, is just south of Twelfth street road, and comprises a strip of land varying from half a mile to a mile and a half in width, and extending 10 miles west from the river. Here the seepage and surplus waters from the outer extremities of the Utah and Salt Lake, the South Jordan, and the North Jordan canals have collected to an alarming extent. Indeed, the damage has gone so far that a chain of lakes has formed, presenting a water surface of fully 1,000 acres. The area affected is not less than 10 square miles.
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> The seepage and waste waters from the canals account in great measure for the 10 square miles of good land which has already been ruined by seepage and alkali. It has been shown that the water is of good quality, and the lands of the upper benches are naturally free from any great excess of alkali; but the continual seepage from the canals during the growing season for a great many years has transported a quantity of salt to the lower levels.

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[a] A Soil Survey in Salt Lake Valley, Utah, by Frank D. Gardner and John Stewart. Field Operations, Division of Soils, 1899, pp. 77–114. This report was also published as Bul. 72 of the Utah Experiment Station.

The necessity of careful construction of the canals, especially those on gravelly lands, and the desirability of preventing the waste water from flowing over the lower levels is sufficiently obvious without further comment.

The application of water on the lowlands west of Salt Lake City, where there is a large amount of alkali in the lower depths, has been attended with very disastrous results to crops. The salt has quickly risen to the surface and, even where the surface foot was originally free from alkali, the crops have been completely ruined in the course of two or three years.

* * * * * * *

Attention has already been called to the necessity of underdrainage for protection against injury from seepage waters and alkali and for the reclamation of injured lands. Irrigated lands in the Salt Lake Valley are worth at least from $60 to $100 per acre. Land immediately adjacent to Salt Lake City, especially if held as surburban property and if free from alkali, would be worth much more than this. There is plenty of good tile clay in the vicinity of Salt Lake City, and tile could be manufactured for the farmer at a reasonable cost. It is estimated that it would cost from $10 to $20 an acre to underdrain these lands, which under the present conditions have a merely nominal value.

During the course of this investigation particular attention was given to the possibility of reclaiming the vast tract of 125 square miles between Salt Lake City and the Great Salt Lake. The levels of the railroad surveys and of the canal companies were freely consulted. At Salt Lake City the level of the Jordan River is about 20 feet above the level of the water in the Great Salt Lake. The distance across is about 14 miles. There is a slight ridge, however, running a little west of north about a third of the way across from Salt Lake City. From the crest of this ridge to the Great Salt Lake there is a uniform fall of approximately 3 feet to the mile. This would be ample for the main drainage canals, as the irrigating canals have only about one-half this fall. Furthermore, there are many draws, already 4 to 8 feet deep, extending like fingers through this area, which with little additional work could be made to answer for a considerable part of the drainage system.

On account of the impervious nature of the Jordan clay, the great salt content, and the low elevation it would not be advisable to attempt drainage over this class of land at the present time. Subtracting this area, estimated at 35 square miles, from the 125 square miles, the value of the remaining lands, if thoroughly drained, would be about $3,000,000. At present they have merely a nominal value.

Since the publication of this report no step has been taken by State or county authorities toward any general scheme of drainage and reclamation, and so far as the knowledge of the Bureau goes no work of any moment has been attempted by individuals.

In order to bring a matter of so much importance to the attention of the farmers, as well as of the community at large, an experiment to demonstrate the value of drainage in alkali reclamation was planned by the Bureau of Soils. In the carrying out of the work the Utah Experiment Station entered into cooperation with the Bureau of Soils, and in 1902 a tract of 40 acres, belonging to Mr. E. D. Swan, was selected for the demonstration. This tract lies 4 miles west of Salt Lake City, in sec. 5, T. 1 N., R. 1 E.

The land, at the time work was commenced, was all strongly impregnated with alkali salts, and had nothing growing upon it except a few alkali weeds, the most prominent of which was greasewood (*Sarcobatus vermiculatus*). The land was considered valueless by the farmers of the neighborhood.

The tract lies on the east side of Williams Lake, and at its highest point has an elevation of about 8 feet above the part of the lake bed adjacent to the tract.

The cost of this installation was as follows:

270 feet 10-inch tile, at $100 per M feet	$27.00
300 feet 8-inch tile, at $64 per M feet	19.20
520 feet 6-inch tile, at $27.50 per M feet	14.30
6,580 feet 4-inch tile, at $17 per M feet	111.86
2,890 feet 3-inch tile, at $13 per M feet	37.57
Fittings	2.80
Freight on 3 carloads, Ogden to Buenavista	60.00
Cartage and scattering tile	17.50
606 rods ditch, at 50 cents per rod	303.00
67 rods main ditch, at 54 cents per rod	36.30
673 rods covering with team	19.50
150 feet outlet ditch (open)	6.00
One-fifth cost of tools	5.00
Total cost	660.03

The average cost of the drainage system completed was $16.50 per acre, and it is believed that the drainage of larger tracts could be accomplished at about the same cost.

The tract is composed of a surface soil of a silty loam and sandy loam, with a depth ranging from 12 to 18 inches. The underlying material is a heavy clay. A very shallow sand stratum occurs at a depth of 4 feet over the greater part of the tract. The lower or lakeward half of the tract is underlain at an average depth of 26 inches by white calcareous hardpan from 1 to 2 inches in thickness.

With the above soil and hardpan conditions it was deemed advisable to place the drains 150 feet apart, and this interval was used, except in one instance. The systems for the 40 acres includes eight lateral drains and one main drain. Each of the laterals is 1,250 feet long, and is laid with 850 feet of 4-inch and 400 feet of 3-inch draintile. The exception already referred to is in the interval for lateral No. 8, which is laid 200 feet from the nearest lateral, the object being to study its efficiency under such conditions of soil as exist in this tract.

The main drain is put in across the lower part of the tract, 20 feet from its west side, and is met by seven of the laterals. This drain was laid with 270 feet of 10-inch, 300 feet of 8-inch, and 520 feet of 6-inch tile.

Over the greater part of the tract the drains were laid at a depth of 4 feet. The drains were laid on a grade of not less than one-tenth foot in 100 feet, except where 3-inch tile was used, when the grade was somewhat higher. Flooding has been carried on systematically, the land being divided into checks and plats by levees and each plat treated in rotation. During each flooding water has been added to an average depth of 4 inches. The movement of the water into the soil has been regular and, considering the character of the clay subsoil, rapid, and the drains have quickly filled after the floodings and have run freely throughout the experiment.

After the installation of drains under the land in question, a partial leveling of the tract was undertaken. The tract represented virgin soil conditions and had a more or less uneven surface and was generally covered with greasewood. The grade of the land running diagonally from the intake weir to the outlet ditch was rather heavy, being about 8 feet between the intake weir and the bottom of Williams Lake. The Utah Experiment Station was to clear the land and level the surface. This was rather difficult and expensive, owing to the fact that the tract had at one time been plotted and had had streets graded upon it and a railroad embankment of some 4 feet in height and nearly a rod wide ran diagonally across the tract. After the land had been cleared, some leveling was done and the land divided into small plots or checks by means of levees.

The preparation of the land surface for flooding operations is an important step in the reclamation from alkali. With level land the task of preparing inclosures is comparatively easy, and large plots of land can be inclosed by a single low levee or ridge. Land of greater grade or slope, however, requires either that the land be inclosed in many levees, thus making small plots, or that, if a less number of levees be constructed, the land within each plot be leveled to practically the same elevation throughout. Too much attention can not be given to the initial preparation of the land, since uniform leaching from alkali can only be accomplished on lands well leveled or lands which can be flooded to a uniform depth during reclamation.

During the season of 1903 the land was flooded once each week, with occasional longer intervals when the supply canal was being repaired or during times when the land was being plowed or the levees repaired.

Before any water was applied to the tract a detailed survey was made to determine the alkali content of the soil. This initial survey was made in September, 1902. The land was then flooded once and allowed to remain until the next spring.

In May, 1903, before work was commenced, a second survey was made; and a third survey of the tract was made in October, 1903, after the close of the season's operations.

The following table shows the volume of water added to the tract from September, 1902, until October, 1903. The table shows also the volume of drainage over the outlet weir, and the salts (alkali) removed from the tract in the drainage water. The results are obtained from continuous measurements and daily collections of water samples for the entire period.

Total quantity of water used in flooding the tract, quantity flowing off through drains, and quantity of salts removed in drainage water.

Month.	Volume of water added to tract.	Volume of drainage water from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet.*	*Pounds.*
1902—September	284,400	158,700	152,200
October	940,000	265,000	195,100
November	[a]171,300	251,000	353,800
December	[a]166,500	139,700	187,800
1903—January	[a]291,800	257,300	391,200
February	[a]136,400	174,400	214,800
March	[a]132,000	428,000	590,700
April	[a]112,000	26,900	26,500
May	[a]576,900 760,900	521,500	567,100
June	[a]106,000 676,500	274,500	345,200
July	[a]36,580 1,691,970	480,490	556,459
August	2,122,160	814,890	1,221,742
September	2,352,920	1,195,976	1,654,115
October	351,290	663,420	840,981
Total	10,909,620	5,651,776	7,297,697

[a] Fell as rain or snow.

Total volume of canal water used	cubic feet	9,180,140
Volume falling as rain and snow	do	1,729,480
Total volume from above sources	do	10,909,620
Total water used	acre feet	250.4
Salts added in the canal water	pounds	900,000

The total volume of drainage was 5,651,776 cubic feet, or 51.8 per cent of the water added to the tract. This 51.8 per cent drainage water carried 3,648 tons of salts over the outlet weir. The remainder of the salts removed from the tract have passed into the deeper subsoil and been carried away by the natural subdrainage.

The above record shows the results obtained during 1903 up to October 31. During the season of 1904 the operations on the land were continued, and during that season a practical seed test was applied to the tract.

The following table shows the volume of water added between October 31, 1903, and October 1, 1904:

Total quantity of water used in flooding the tract, quantity flowing through the drains, and quantity of salts removed from October 31, 1903, to October 1, 1904.

Month.	Volume of water added to tract.	Volume of drainage from tract.	Salts in drainage water.
	Cubic feet.	*Cubic feet.*	*Pounds.*
1903—November	563,376	113,137	126,364
December	40,656	50,376	43,953
1904—January	217,800	26,396	18,912
February	299,112	382,628	475,631
March	187,308	380,114	521,974
April	255,552	258,519	382,335
May	382,974	60,903	61,466
June	44,970 618,172	68,132	31,487
July	87,120 1,610,807	430,459	385,364
August	35,820 1,920,726	774,285	711,021
September	20,320 802,153	579,215	579,215
Total	6,986,866	3,124,164	3,337,722

	Cubic feet.
Total volume canal water used October 31, 1903, to October 1, 1904	4,951,858
Volume falling as rain and snow	2,035,008
Total volume for above period, all sources	6,986,866

For the above period the total volume of drainage was 3,124,164 cubic feet. The volume of drainage was 44 per cent of the water added to the tract. This quantity of drainage water carried 1,669 tons of alkali salts over the outlet weir. The remainder of the water reaching the tract (56 per cent) was in part carried below the drains and in part lost through surface evaporation.

From the initial installation to October 1, 1904, we have the following:

Water added to November 1, 1903	cubic feet	10,909,620
Water added from November 1, 1903, to October 1, 1904	do.	6,986,866
Total volume of water added	do. acre-feet	17,896,486 410
Salts eliminated to November 1, 1903	tons	3,648
Salts eliminated from November 1, 1903, to October 1, 1904	do.	1,669
Total tonnage of salts removed	do.	5,317

The initial tonnage of alkali in this tract in September, 1902, by a careful alkali survey, was 6,651 tons. From the above record it would seem that about all the alkali had been filtered from the tract to a depth of 4 feet. Especially does this seem true when we consider that this tonnage was obtained from little more than half of the water actually added to the tract. One factor, however, remains undetermined, viz, the volume of water lost by surface evaporation.

Certain phenomena enter into the work which tend to show that the salt removed over the outlet of the tract will finally exceed the actual tonnage originally present. We find the reclamation from alkali is limited to the 40 acres in question, but that the effect of this drainage system is far-reaching. Unmistakable evidences appear which show that the land lying contiguous to this tract has been most definitely acted upon in regard to its alkali content by the drains installed on the 40 acres. Lands lying above this tract which in years past have never produced crops have during the past season yielded almost normally. The drains near these lands have carried from them their underground water and the alkali which it contained.

The results obtained at the outlet weir show an unmistakable movement of alkali, and the changes which have taken place in the chemical composition of the drainage water furnish valuable data for future work along the lines of reclamation.

The following table gives the quantity of alkali in the tract, as shown by the surveys taken at different times:

Quantity of alkali in different depths of soil on certain dates.

Soil section.	September, 1902.		May, 1903.		October, 1903.		October, 1904.	
	Alkali in 40 acres.	Part of total.	Alkali in 40 acres.	Part of total.	Alkali in 40 acres.	Part of total	Alkali in 40 acres.	Part of total.
	Tons.	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*	*Tons.*	*Per cent.*
First foot	1,363	20	499	14	101	8	38	4
Second foot	1,540	23	650	19	183	15	128	13
Third foot	1,766	27	1,066	31	330	28	212	24
Fourth foot	1,982	30	1,265	63	607	49	500	57
Total	6,651	....	3,480	....	1,221	....	878	....

The alkali removed from the first foot of the tract between September, 1902, and October, 1904, was 97 per cent of the total quantity originally contained; from the second foot, 91 per cent; from the third foot, 87 per cent, and from the fourth foot, 75 per cent. These figures show that to 4 feet depth there has been 86.8 per cent of the original alkali removed from the entire tract.

Compared with its condition in September, 1902, the first foot of the tract contains only 3 per cent of the alkali originally carried; the second foot, 9 per cent; the third foot, 14 per cent, and the fourth foot, 25 per cent. We find from this that the alkali has been removed most rapidly from the lower depths of the soil. We must remember that the alkali in the first 3 feet of soil must pass through the fourth foot in its movement downward. The fourth foot we find has been traversed by the alkali lying above it, and has yet lost 75 per cent of its own original alkali content. The extreme saltness of the percolating water has, however, made the final elimination of alkali from the lower 2 feet of soil progress more slowly than in the surface 2 feet. At the present time little more alkali remains in the first 2 feet of soil, and the elimination from the third and fourth should go on more rapidly.

The following table shows the increased acreage of soil containing a low percentage of alkali. The columns headed September show the original acreage, while the columns headed October show present acreage:

Acreage of land of different grades of alkali September, 1902, and October, 1904.

Per cent alkali present in soil (grade).	First foot.		Second foot.		Third foot.		Fourth foot.		All 4 feet.	
	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.	September, 1902.	October, 1904.
0.0-0.2	None.	38.8	None.	27.6	None.	17.0	None.	11.5	None.	23.7
0.2-0.4	3.0	None.	0.4	8.2	0.1	11.5	0.1	9.0	0.9	7.2
0.4-0.6	13.3	None	2.3	3.2	.7	5.3	1.3	6.0	1.9	3.6
0.6-1	10.7	None.	8.0	None.	3.9	3.5	6.2	5.3	7.2	2.2
1-3	16.8	None.	19.7	None.	22.6	1.7	18.1	7.2	19.3	2.2
Over 3	5.0	None.	8.4	None.	11.5	None.	13.1	None.	9.5	None.

Operations for reclamation in 1904 began in April. An alkali survey made at that time indicated that the tract was in a fairly good condition as to alkali content.

Preparations were made for a crop test, and on May 10 the Utah Experiment Station began seeding the tract to three varieties of grain—wheat, oats, and barley—one-third of the tract to each variety. The seeding operations were finished on the 24th of May.

The general tilth of the land was not altogether favorable. The soil of the tract partakes somewhat of adobe characteristics, tends to bake or harden, and does not readily respond to cultivation. The flooding operations carried on the previous season had a tendency to compact the soil and disturb somewhat its physical properties. The tendency to bake is, however, a common characteristic for all soils in the vicinity at present under cultivation.

The first irrigation was given to the crop June 15. The part of the crop sown in early May had remained in the ground during this time without any appreciable amount of moisture. The surface of the land had hardened, and an examination showed that, while the seed had germinated, the young plants often failed to get through the upper hardened soil layer, and lay alive, though wrinkled and distorted, beneath the baked surface. No material growth was made prior to the first irrigation. Of the three grains sown the wheat made by far the best showing. This crop was, however, sown last, and did not receive water until twenty days after being planted. A close study of the soil and crop during May and early June showed that here and there small patches of alkali remained. These spots were strongly enough infected with alkali to prevent the germination of a part of the seed, though the general appearance of the soil was satisfactory.

The first irrigation given the crop materially improved the physical condition of the soil. An estimate on the germination of the crop showed that about 85 per cent of the seed had sprouted. Of the 40 acres about 15 per cent showed a thin stand due to alkali. The entire field headed short and showed the untoward influences of late seeding, late maturing, and the effects of alkali still remaining in the soil. One-half of the tract was ploughed under in early August and the remaining half in early September; this being done to improve the soil tilth.

The alkali found near the surface on the Salt Lake tract in April, 1904, owed its presence largely to the uneven surface of the land. Slight ridges occurred here and there and prevented uniform flooding. During the past two seasons numerous evidences have shown that the maximum quantities of salts were eliminated from the lands that were most deeply and continually flooded.

During September, 1904, the entire tract was turned over to the Utah Experiment Station for future cultural trials. Ten acres were seeded to winter wheat. The seeding was completed about the middle of October, much too late to secure the most favorable conditions, as at this time no water was available for irrigation and the soil was so dry that the grain lay in the soil for a long time before fall rains furnished sufficient moisture for the seed to germinate. In the spring of 1905 most of the wheat had made a good growth, but was thin and uneven in some places. The heads filled nicely and the wheat was pronounced by all who saw it a fine quality of good heavy wheat. The remaining 30 acres were planted to alfalfa and a great variety of other crops, including potatoes, corn, berseem, beans, hemp, sugar-beets, oats, barley, and spring wheat. As the land even at this late date had not been sufficiently leveled to irrigate the crops to good advantage, many of the crops suffered in consequence. In all parts of the tract, however, where sufficient water could be given the growing crops, the results were very gratifying. The crops made good growth and the yields were all that could be desired. In January, 1906, 13 acres of the tract had a good stand of alfalfa and 4 acres were in wheat. Systematic flooding was not carried on during 1905, but the tract was irrigated once a week the early part of the summer. Within a few hours after the irrigation water was turned on, the drains responded with an increased flow, showing that they were still as effective as when first installed. Careful tests made in June, 1905, and again in September, showed that the alkali content had changed but little, if any, from the preceding year.

FRESNO TRACT, CALIFORNIA.

Early in 1903 the reclamation of a 20-acre tract was undertaken near Fresno, Cal. From 1903 to August, 1905, the work was in charge of W. H. Knox. Since the later date W. W. Mackie has been in charge. Circular No. 11 was published by this Bureau in September, 1903, which described the conditions at that time. The following report, taken largely from this circular, describes the progress of the reclamation work to date.

At the time of settlement of the country south of Fresno there was little indication of the presence of alkali in the soil and no one then suspected that serious damage would result from irrigation. When, after a few years, alkali commenced to show in the vineyards and orchards, the attention of thoughtful men was directed toward remedying the evil, but up to the time of undertaking the experiment in 1903 nothing effective had been accomplished.

In 1900 a party from the Bureau of Soils spent a season in studying the soil conditions around Fresno, and in a report, embodied in the Report on Field Operations of the Division of Soils for 1900, recommended drainage, with frequent cultivation and copious irrigation during reclamation, as the solution of the alkali problem.

The Bureau selected a 20-acre tract of land belonging to S. M. Toft and N. H. Hansen, situated on Fig and Central avenues, about 4½ miles south of Fresno, and entered into cooperation with these gentlemen to demonstrate to the people of the Fresno district that alkali lands can be economically reclaimed.

The history of this land, as given by the owners, is as follows: The northern part of the tract was settled upon by Mr. Toft in 1876 and at that time showed no sign of alkali. In 1889 Mr. Toft bought an additional 20 acres at $350 an acre, an average value for land in that vicinity at that time. The southern part of the tract was first settled upon in 1862 by Mr. Hansen, and at that time was partially alkaline. It had never produced good crops. In 1890 alkali commenced to show on the northern part, and in 1898 and 1899 it was practically abandoned.

The tract lies in a level district where it was impossible to obtain a gravity outlet for the drainage water, except by digging a drain 2 miles long, so in order to raise the drainage water to the surface of the ground a chain pump operated by a water wheel was installed on Central Canal, where it crosses Fig avenue. A drainage system of this kind is admittedly not so desirable as one in which a gravity outlet can be maintained.

Three-inch, 4-inch, and 6-inch tile were laid over the tract at an average depth of a little over 3 feet and 150 feet apart. The original intention was to use nothing smaller than 4-inch tile, but the makers were unable to supply enough tile of this size, so the deficiency was made up by using 3-inch tile. It was found impossible to lay the tile during the summer season, owing to the nearness of the water table to the surface and the resulting condition of the subsoil, which was too soft to permit the digging of a deep ditch. The work of ditching was commenced in December, 1902, and was completed in February, 1903. The cost of ditching, tiling, and all incidentals except the cost of pump and water wheel amounted to $16.50 per acre. The contract for the tile delivered in Fresno was, for 3-inch tile, $24 per thousand; for 4-inch tile, $32 per thousand; and for 6-inch tile, $72 per thousand.

At the time of the installation of the drains 18 acres of the land contained too much alkali to produce a crop. Scattered over a part of the tract were small patches of alfalfa and an occasional fruit tree—remnants of former cultivation. About March 1, 1903, irrigation was commenced. The land was divided into 30 checks, the size of each check depending upon the slope of the land. The largest checks, those on the level land, are about 2 acres in extent, while on the steeper slopes they are less than half an acre. The object was to divide the land in such a way that it could all be kept under water to a depth of 4 inches, and the reclamation was to be accomplished by maintaining the water at this depth until enough alkali had been washed out of the soil through the drains to enable a crop to be grown.

During the progress of flooding many difficulties were met, among them that of keeping the tiles from partially filling with sand and silt. Precaution was taken in laying the tile to put them in so the joints would be close, hay was thrown over the tile in the ditch before covering with earth, and a ridge of earth was thrown up to prevent the water from standing directly over the drains. In spite of these precautions the soil, which is very light, was so easily moved by water that it seemed to enter the joints almost as readily as did the water. This resulted in some of the drains becoming clogged, and it was necessary to relay a portion of the tile. Most of the trouble was with the 3-inch tile, which is admittedly too small for use in soils of the light and silty character of the Toft-Hansen field. It is thought that there will be more or less silting up of the tiles whenever they are used in the sandy and white ash soils of the Fresno district, and it is recommended that every possible precaution be taken in putting them in. Much of the trouble may be obviated by using no tile smaller than 4 inches or preferably 6 inches in diameter, and by giving the laterals such fall that the velocity of the water will be great enough to wash out the sand as rapidly as it enters the joints. The tile on the Toft-Hansen tract have a fall of 1 in 1,000 and the velocity of the water flowing through them is not sufficient to remove the sand.

During the season of 1903 the flooding was carried on from March to August. In 1904 flooding operations were resumed on February 11 and continued until August 22. Much of the land was reclaimed to such an extent during 1903 that crop tests were made. In July, 1903, one check or plot was sown to sorghum and one check to alfalfa. Clover did not succeed well, but 50 per cent of a stand was secured on 3 acres. In November, 1903, alfalfa was sowed on 3 acres. This started nicely, although it was somewhat damaged by frost.

In April, 1904, the first cutting of alfalfa was made. The total yield was about half a ton. Immediately following this cutting gypsum to the extent of about 400 pounds per acre was applied. This acted as a stimulant to the plant and also improved the physical condition of the soil. A second cutting of alfalfa was made in May, yielding about 2 tons. A third cutting was made in June and a fourth in July, the yield being about 3½ tons at each cutting. The fifth crop was a failure, owing to the depredations of the army worm. A sixth cutting was made in October, yielding 2½ tons. The total yield for the season and the value of the same are given below:

	Pounds.
First cutting, April	1,000
Second cutting, May	4,000
Third cutting, June	7,000
Fourth cutting, July	7,000
Fifth cutting, August	1,000
Sixth cutting, October	5,000
Total	25,000

12½ tons, at $7.50 per ton=$93.75.

On the north part of the tract some plots were sown to wheat. In June the wheat on checks Nos. 31, 32, 33, and 34 was cut for wheat hay, yielding as follows:

Checks 31, 32, 33—5 tons wheat hay, at $8.50 per ton	$42.50
Check 34—11 tons wheat hay, at $8.50 per ton	93.50
Total	136.00

Total value of crop of alfalfa and wheat, $229.75 from approximately 7 acres—$32.82 per acre.

An alkali survey, made in October, 1904, showed a total of less than one-fourth acre containing over 0.2 per cent total soluble salts. Of the black alkali there was approximately half an acre containing over 0.03 per cent black alkali and less than one-eighth acre containing more than 0.10 per cent. In every case the hardpan is close to the surface. Not only was there a marked change in the quantity of alkali the soil contained, but an even greater change in the general appearance and physical condition of the soil. The slick greasy appearance had given place to a dark, rich appearance, the tendency of the soil to bake had gone, and in its place was a friable granular condition.

This shows in conclusive manner the good effects of two seasons of flooding on a tract of land that had been practically abandoned on account of the rise of alkali. Alfalfa was sown on much of the land late in the fall of 1904, and by the spring of 1905 had made a fine growth. From three cuttings of alfalfa 25 tons of hay were harvested, valued at $5 a ton. Later in the season the troublesome Bermuda grass began to make its appearance and crowded out some of the alfalfa. Three acres were planted to White Australian wheat that produced a crop of 5 tons of hay, valued at $8.50 per ton. Smyrna barley planted on 3 acres produced 8 tons of hay, valued at $8.50 per ton. While the crop returns on this tract have been very satisfactory, showing that practically all the alkali has been leached from the soil, there are three factors that have retarded the final success of the work. These are the existence of hardpan in some places, which retarded the movement of water through the soil when the tract was being flooded; the clogging of the tiles, caused by the fine micaceous silt that enters them almost as readily as the drainage water; and the difficulty of removing the immense volume of drainage water. The presence or absence of layers of hardpan through the soil can only be determined by a careful study of any particular field. Its presence affects the rapid reclamation of any piece of land, especially when the hardpan is near the surface. On spots underlain at a depth of less than 2 feet by a firmly cemented hardpan it was found very difficult to leach the alkali beyond this layer. Even after the alkali had been leached through the hardpan the crop of young alfalfa was badly scalded by irrigation during the extremely hot weather. To overcome the difficulties caused by the tiles becoming clogged with silt and to remove the great inflow of ground water rising shortly after water is turned into the canals it was considered advisable to install a new drainage system, much deeper than the original. The work of installation was completed in the fall of 1905. More fall was given all lines of tile. No tiles smaller than 4 inches in diameter were used, and silt boxes were put in at the junction of all laterals with the main drain. A steel-wire cable, to which a brush can be attached, was also laid in all lines of tiles. This can be drawn through the tiles as often as seems necessary to keep them free from silt. The owners of the land have also doubled the capacity of the pump, so that in the future it should be adequate to remove all the drainage water. It is thought that no further trouble will result from the tiles silting or the ground water rising above the tiles.

NORTH YAKIMA TRACT, WASHINGTON.

In 1901 the Bureau made a detailed study of the soil, underground water, and alkali conditions in the Yakima Valley, Washington. In the report of this area Jensen pointed out the extent of the damage caused by alkali and suggested methods looking to the reclamation of such lands. In the chapter on Drainage and Reclamation of Alkali Lands Jensen writes as follows:

> If the soil is originally alkaline, there is but one sure and permanent cure for the trouble—that is, to dissolve out the excess of soluble salts by moderate but frequent application of good water, at the same time draining the water out of the subsoil, the process to be continued until the excess of salt has been removed.
>
> More especially is this true in case of the areas that have become damaged by alkali by allowing the subsoil water to come near enough to the surface to form an accumulation of salt by evaporation, in which class are the damaged lands in Wide Hollow and Atanum

Valley. The salts accumulated in these places are alkaline carbonates or black alkali, and an examination of the seepage water shows that it carries in all cases more than a normal amount of bicarbonate, but no normal carbonate. Examination also shows that the seepage or subsoil water is sufficiently near the surface to be brought up by the capillarity of the soil grains to the surface, there to be evaporated. There can be but one consequence—the comparatively harmless bicarbonate will lose through evaporation some of its carbon dioxide and be converted into the normal carbonate. As the soil is light in texture in this area this capillary action goes on quite rapidly; but, on the other hand, there is this advantage—the water can be removed from it correspondingly easier.

The alkali in the Wide Hollow and Atanum areas has originated from the seepage water brought down from the lands above. It will be quite useless here to try to effect a permanent cure by attempting to change the character of the salt by application of some other salt—as calcium sulphate, for instance—for, while this will change some of the black alkali to white alkali, it only adds more salt to a surface foot, already containing an excess, without in the least decreasing the tendency to form black alkali, which will continue to accumulate as long as the subsoil waters containing bicarbonate are near enough the surface to be evaporated.

In some areas in Wide Hollow the dangerous practice obtains of allowing the seepage water from above to subirrigate the land. This is a very good method of increasing the salt content of the soil, and the nearer the water approaches the surface and the longer the practice is continued the more salt there will be accumulated.

The Wide Hollow waste slough forms an excellent natural drainage channel for the lower portion of Wide Hollow, from sec. 36, T. 13 N., R. 18 E., and below. This goes through much of the salty area, and is from 5 to 10 feet below the surface of the soil. The soil is light in texture, readily permitting the water to percolate through it, and frequent applications of water, with a few drains about 4½ to 5 feet deep, would accomplish much toward reclaiming the land. Another good natural-drainage channel is the northern branch of Atanum Creek. It does not drain as large an area of the alkaline lands as the waste slough, neither is it as deep, but much of the land in the eastern part of T. 12 N., R. 18 E., could be reclaimed by draining into it. Atanum Creek itself would take care of the area between it and the branch just mentioned. A drain 4½ to 5 feet deep, containing rocks covered with willows, and this in turn covered over with soil, would effect this, but tiles will be found more economical. Even open drains, where they would not interfere seriously with cultivation, would serve very well.

The area selected for demonstration in the Yakima Valley is located about 3 miles south of North Yakima and contains 22½ acres. L. C. Holmes has had charge of the experiment from 1903 to the present time. It comprises a part of the southwest quarter section of sec. 31, T. 13 N., R. 19 E. The soil consists of a fine sandy and silty loam. It is light and porous and is made up to some extent of volcanic ash. Calcareous hardpan was encountered at a depth of from 2 to 2½ feet. The tract was virgin land, which supported only salt grass, greasewood, and some sagebrush.. It was of no value except for pasture land and possessed a nominal value of from $10 to $15 an acre. Since good alkali-free soil in the valley ranges from $150 to several hundred dollars an acre and is very scarce, the importance of reclaiming such land, if possible, is at once apparent. The soil contained large quantities of sodium carbonate, sodium chloride, and sodium sulphate. The black alkali was largely in the first foot, while below the hardpan little or no alkali was found.

A complete drainage system was installed early in the summer of 1903. Six lines of 4-inch drains were laid 150 feet apart. These discharge into Wide Hollow Creek, which flows past the southern end of the tract. The tiles were laid at an average depth of from 3½ to 4½ feet, with a fall of 2½ feet in 1,000 feet. The tile was purchased in Seattle, Wash. On account of the light silty nature of the soil the joints between the tile were covered with tar paper. Experience at Fresno, Cal., had shown that with light soils every precaution should be taken against the silting of the tile, especially during the first few months that flooding is carried on, or until the earth settles firmly over the tile. The actual cost of the installation of the drainage system was about $21 an acre.

Flooding was commenced July 15, 1903, and continued throughout the irrigation season until about November 1. Considerable trouble was experienced with the unstable banks, the loose soil over the tile, and the steep slope of the land. The soil when freshly thrown up in banks or ridges does not hold water well, and with the slope of the tract it proved a difficult matter to hold the water on the land. Frequent breaks in the banks occurred and the lines of tiles had to be carefully inspected to prevent serious damage from the water washing earth into them. During the season of 1903 upward of 8,000,000 cubic feet of water was used, or sufficient to flood the entire tract to a depth of 8⅓ feet. Of this quantity approximately 25 per cent was carried away through the drains. The remainder passed below the drains into the deep subsoil, while part was undoubtedly lost through evaporation. Careful estimates showed that approximately three-fourths of the total alkali had been removed from the soil to a depth of 4 feet as a result of the season's flooding.

The work of flooding was resumed May 30, 1904, after the tract had been plowed and some of the checks had been more thoroughly leveled. During the season of 1904 the water supply was not as abundant as in the previous season, but about 4,500,000 cubic feet were used—sufficient to flood the entire tract to a depth of 5 feet. On account of the low condition of the water table only a small amount of this water passed through the drains.

An alkali survey made in October, 1904, showed that the quantity of alkali had been further reduced from the total amount originally present in the soil. To test the condition of the soil, the land was well prepared, and wheat at the rate of 2 bushels per acre was sown in the fall of 1904. Late in October, 1904, about 85 per cent of the tract was in good condition, as indicated by the young wheat crop.

The spring of 1905 found a part of the wheat, which had given evidence of a good start the previous fall, damaged by alkali. Nearly all the wheat which survived had a good color and was making a rank growth, but the stand was somewhat irregular. Rank grain was often found upon the sides of banks, but a few feet away the growth was patchy. The best soil, so far as the alkali content was concerned, often gave the poorest growth of wheat. These irregularities may be accounted for by one or more factors, such as the varying thickness of the hardpan, preventing thorough leaching of the soil, the leveling off of soil from one part of a check to another, or lack of aeration.

Alkali appeared on some of the land, especially on the high spots. Additional leveling was necessary to flood the entire tract evenly. The wheat crop was cut for hay, yielding about 25 tons, valued at $200. Some of it was over 6 feet in height. Flooding of the tract was begun about May 15 and continued until about September 30. The available water supply for flooding was not as great as in the years 1903 and 1904. It was estimated that over 6,000,000 cubic feet of water was used during the season, sufficient to cover the tract to a depth of 7 feet. The six lateral drains discharged water quite irregularly, but it was estimated that the total discharge was approximately 25 per cent of the amount applied in flooding. Usually 5 or 6 checks were selected and flooded repeatedly without giving the alkali a chance to return to the surface. Much trouble was again experienced with the unstable banks.

An alkali survey made during October showed that about one-fifth of the tract contained less than 0.05 per cent; three-fifths contained from 0.05 to 0.1 per cent, and the rest more than 0.1 per cent of alkali. The soil was in good physical condition, and its natural good tilth had apparently not been destroyed by the repeated floodings.

During September and the early part of October, 1905, the tract was plowed and seeded to wheat and alfalfa, 1 bushel of wheat and 15 or 16 pounds of alfalfa being used per acre. The early growth of these crops was quite favorable, but late spring freezes, which occur occasionally in the valley, were so severe that reseeding was necessary on the greater part of this tract.

TEMPE TRACT, ARIZONA.

A report on the soil survey of a part of the Salt River Valley, published in 1900, pointed out the trouble with alkali experienced by the farmers and made specific recommendations for the reclamation of affected lands, but no attempt has been made in this direction. Since the Bureau believed that this would be an excellent place for demonstration work, a tract of 20 acres was selected in 1904. The land is situated about 2½ miles south of Tempe. J. F. Warner was placed in charge of the experiment. Prior to 1904 this field was uneven and contained many stumps and various kinds of brush and weeds. At the south end there were 2 or 3 acres of alfalfa that produced fair crops, although it contained some spots that were damaged by alkali. During the fall of 1903 barley was sown on part of the tract, but it failed to make much growth on account of alkali. On the north end of the tract there was a heavy growth of the alkali-resistant Bermuda grass in places.

Early in January, 1904, an alkali survey of the field was made, which showed that the alkali was very unevenly distributed over the field. In places the soil contained 3 per cent of alkali to a depth of 4 feet and in other places less than 0.10 per cent was found. The average amount, as shown by a large number of determinations, was 0.88 per cent. The greater part of this was found in the surface foot.

The work of installing the drain-tile system was completed early in March, 1904. The cost of installing the drainage system was as follows:

Tile	$114.50
Freight on tile	313.90
Labor, digging ditches, and laying tile	153.80
Lumber	29.90
Tools	18.25
Total	630.35

From this it will be seen that the single item of freight on the tile amounts to one-half the total cost of installation. No tile could be purchased nearer than southern California. If tile could be manufactured at Tempe, the cost of installing such a drainage system as this would be very materially reduced. The cost of installation amounted to about $32 per acre. Four lines of 4-inch drain tile were laid at a depth of from 3½ to 5 feet. The laterals were placed 150 feet apart and discharged into a main drain at the north end of the field. At the time the drainage system was installed the water table was about 9 feet from the surface. For several preceding seasons the rainfall had been light, and the water table was consequently low. At the time the soil survey was made in 1900 water stood for a part of the year on the surface and was near the surface over the entire tract.

Soon after the drainage system was installed the irrigation water ran low, and but little was accomplished during the early part of the summer of 1904. Heavy rains during August enabled the work of flooding to be resumed. Flooding was continued at intervals until the late fall. In October 9 acres were seeded to barley, and other parts of the tract were seeded to wheat and alfalfa. These crops started nicely, but were somewhat damaged by the exceptionally heavy rains of the early spring of 1905. In places the soil showed a tendency to bake badly, while some few high spots still showed the presence of alkali. During the year 1905 cultivation was practiced to overcome the bad effects caused by the excessive use of water in flooding, and the small alkali spots were further treated to free them from alkali accumulations. A 5-acre tract was seeded to sorghum and made a good crop. In January, 1906, 15 acres of the tract had a fair stand of young alfalfa upon it, which was seeded with barley as a nurse crop. The remaining 5 acres had been planted to barley alone, as in this portion of the tract it seemed advisable to continue growing some annual crop. It was feared that even if a satisfactory stand of alfalfa were secured it would eventually be crowded out by Bermuda grass. After two years of reclamation work this tract had a crop capacity equal to the best lands in the neighborhood, whereas formerly it possessed little value as farm land, and repeated efforts to farm it had resulted in failure.

BILLINGS TRACT, MONTANA.

In June, 1904, steps were taken toward the establishment of another experiment on a tract at Billings, Mont. Billings is situated in the Yellowstone River Valley, and great progress has been made in growing alfalfa for winter feed for the sheep and cattle that pasture on the adjoining ranges during the summer months. Shortly after irrigation was begun alkali commenced to appear, and the ground water rose rapidly, water-logging wide areas of the soil to such an extent that they soon had to be abandoned. An examination of certain parts of the valley made by the Bureau in 1897 and 1898 showed the extent of the damage, and when, in 1902, a detailed soil survey was made around Billings it was found the trouble had greatly increased. Even in the two years that have elapsed since the soil survey was made many fine alfalfa fields have been abandoned and now are heavily incrusted alkali flats. The farmers are fully aware of the seriousness of the situation, and many tracts of alkali land were offered for the demonstration station.

The tract selected is situated 1 mile west of Billings. A. T. Sweet was in charge of the work during 1904 and 1905. The land was plowed many years ago and all attempts made to grow crops were unsuccessful. It was covered partly with a scant growth of greasewood and in places a thick growth of salt grass. It also supported a few alkali-resistant weeds and scattering bunches of prickly pear cactus.

The soil taken as a whole might be classed as a heavy loam, but lacks uniformity and varies in texture from a sandy loam to a stiff clay. The lighter soil is found principally in the central and western part of the tract, but is not continuous over any considerable area, occurring rather in scattered patches. The heavier soil becomes very sticky and difficult to cultivate when wet and breaks into small cubes like adobe when dry. Locally it is known as "gumbo." In places the heavy soil becomes sandy at a depth of 3 or 4 feet, but in other places extends to the gravel. In the Billings drainage ditch, 640 feet east of the tract, gravel is encountered at a depth of 6 or 7 feet and probably extends under the entire tract, but in many places in the vicinity, where it has been reached, it is found to be cemented and almost impervious to water.

At the time installation was begun an alkali survey of the tract was made and the following results obtained, the borings being made to a depth of 4 feet: Fourteen and two-tenths acres, or nearly three-fourths of the tract, averaged over 1 per cent of alkali for the 4 feet; 4.2 acres averaged over 0.6 per cent, while the remainder, 1.6 acres, averaged over 0.4 per cent. The concentration of alkali was found to be greatest in the surface foot and usually decreased with each foot in depth. Taking the first foot alone, 15.8 acres were found to have over 1 per cent, while in the fourth foot alone only 5.4 acres averaged over 1 per cent. The concentration also varied with the texture of the soil, the higher percentage of alkali being found in the heavier soil. The water table varied from 4 to 5½ feet and the ground water was strongly impregnated, tests indicating over 2 per cent of salt in solution. No traces of carbonates were found, only slight traces of chlorides and a small amount of bicarbonates.

No tile could be purchased in the vicinity, and freight rates were almost prohibitive, but the local brickmakers at once recognized that by putting in tile machinery a demand could soon be created for their goods. The situation was canvassed among the leading landowners, and many agreed to purchase tile if it could be cheaply secured. As a result tile machinery was ordered at once and the contract for furnishing the tile to be used in the experimental work awarded to the local manufacturers.

It was soon ascertained that by mixing ground shale with the ordinary brick clay a fair quality of tile could be made. After several hundred feet of tile had been made the tile machine was broken beyond repair and tile was ordered from Kansas City. This considerably delayed the installation of the drainage system. The system consists of five lines of 4-inch drain tile laid 130 feet apart, the outer ones being 70 feet from the edge of the tract. They were laid at an average depth of 4 feet with a grade of from 0.24 to 0.26 foot per 100 feet. They empty into a 6-inch drain tile laid 20 feet from the east end of the tract and having a grade of 0.25 of a foot per 100 feet. The water from this is carried by means of a 6 by 8 inch box to a drainage ditch 660 feet east of the tract. At the junction of the main tile and the outlet is a 4 by 4 inch silt box, while similar boxes have been placed at each of the laterals 500 feet from the junction with the main.

The cost of installing the drainage system was higher than on any of the tracts hitherto installed. The long distance from Billings to Kansas City, where the tile was purchased, greatly increased the cost over what it would have been had the tile manufacturer at Billings been able to fulfill his contract. The hard clay soil was exceedingly difficult to dig and the price of labor in Montana is high compared with other Western States. The actual cost per acre was approximately $35. With the installation of larger and better machinery tile should be purchased at less than one-half the price which the Bureau was compelled to pay in order to complete the drainage system. This of course will greatly cheapen the cost of drainage, while employing farm hands for digging ditches will further reduce the total cost per acre. With tile manufactured in the vicinity it is believed that the cost of such work should not exceed $15 or $20 an acre.

The installation of the drainage system was completed so late that flooding was not attempted during 1904. During the spring of 1905 there was an unusual amount of rainfall in the vicinity of Billings, the precipitation for the months of May and June alone being nearly 9 inches, and while the rainfall delayed the work of preparing the reclamation tract for flooding it was highly beneficial in removing the alkali.

The tract was plowed in the fall and lay fallow until spring, when that part which had been covered by greasewood was found to be in good condition to be cultivated, but that part formerly covered with salt grass was still unworkable and remained as a tough sod.

In June the levees for holding the water on the tract were completed. Water was admitted from a ditch along the south side of the tract by means of three head gates and allowed to flow from check to check by means of boxes. By a proper adjustment of head gates and boxes a continuous flow was utilized. Two weirs were installed, one for the purpose of measuring the water used in flooding, the other to measure the drainage water.

On July 6 water was turned on, and after the checks had once been filled, which required several days, the entire tract was kept submerged almost continuously until September 30. At two short periods during this time, however, it was impossible to secure sufficient water to keep the entire tract flooded, but at no time was the alkali permitted to reaccumulate at the surface.

As soon as possible after the water was turned off an examination of the soil was made. For this purpose about 40 points on the tract were selected, each one being within a few feet of the point from which samples for examination were taken in June. This examination showed that there still remained in the soil an average of only 0.20 per cent of alkali, or approximately one-fifth of the amount which was there when flooding began and about one-seventh of the alkali which the soil contained at the time the tract was selected. An alkali survey made in June, 1905, showed conditions to be much better than they were the preceding autumn, not only in the total quantity of salts, but also in its position. This change is believed to have been due to the leaching of the freshly plowed ground by the spring rains, accompanied by thorough underdrainage.

In June the principal concentration was found to be in the second or third foot, while at the close of the flooding period it was almost uniformly in the fourth foot.

In performing this work sufficient water was applied to cover the tract to a depth of approximately 6 feet. The evaporation from the surface for the flooding period is estimated at 12 inches. The rainfall for the period was too small to be regarded, being only 1.37 inches.

Of the water which passed into the soil, one-half, or 2.5 acre-feet, was delivered at the end of the drain outlet, 40 rods from the tract, while the remainder passed into the country drainage surrounding the tract, or along the line of the outlet.

During the flooding season the salt content of the drainage water decreased from 900 to 325 parts per 100,000. As the tests show so little alkali remaining in the soil, a crop test will be made as early in the spring of 1906 as weather conditions will permit. This will show in a conclusive manner how far the actual reclamation has progressed and to what extent the tilth of the soil has been damaged by several months' flooding.

CONCLUSION.

From the above accounts of the various demonstration experiments it will be seen that where the work has continued for any considerable time there is every reason to believe in the ultimate success of this method of alkali reclamation. The expense of the work has in some cases been considerable, but it is the belief that it has been justified by the results obtained. In each case tracts of land were selected that were practically worthless on account of accumulations of alkali and also where little if anything was being done to check the damage being caused by alkali. In each of the five districts the alkali problem is a very serious one, and thousands of dollars have been lost through the ruin of once valuable lands.

It will at once be seen that the first step to be taken in reclaiming alkali land is to insure thorough underdrainage in the soil, and that in order to accomplish this lines of drain tile have been used, even though it involved the outlay of considerable capital. By many it will be asked, Was this expensive system of underdrainage necessary? Could not the same method as employed by the Pima Indians be used and the same results be obtained in each case? Again it will be urged that many of the farmers in the alkali districts are in an impoverished condition and can not afford to expend much money to reclaim their lands. Why is drainage necessary at all on the open porous sandy soils that are so prevalent in the arid portion of the country? In districts where the underground water is many feet below the surface undoubtedly the reclamation of alkali lands can be successfully accomplished without installing an underdrainage system. This may be the case, especially on high bench lands. By carefully leveling such lands and using sufficient water the alkali can be washed into the deep subsoil, and even the most sensitive crops can then be grown.

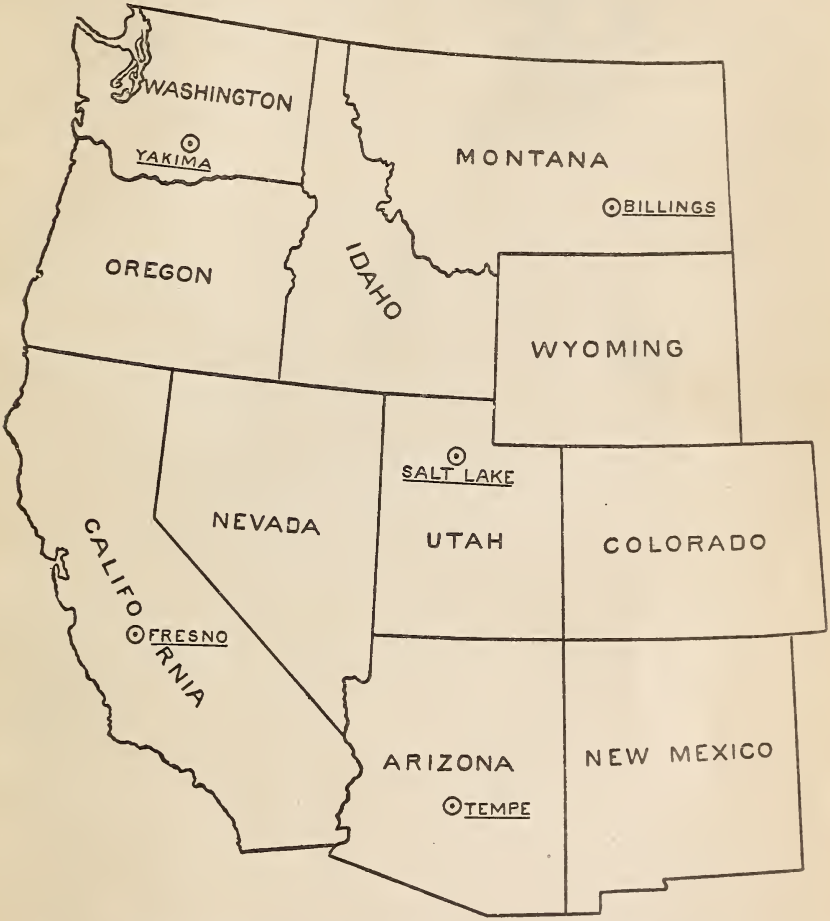

FIG. 13.—Location of alkali land reclamation experiment tracts, May, 1906.

Unfortunately the localities where excessive amounts of alkali have accumulated with a deep water table are comparatively rare. Generally the greatest accumulations of alkali in irrigated districts are where seepage waters have raised the water table until it is dangerously near the surface. Frequently it has been found that the damage and consequent abandonment of the land is caused by a combination of alkali and seepage waters. To attempt to reclaim such lands without lowering the water table is not to be generally recommended. Even with the surface soil free from alkali, the shallow water table would be a constant menace, since evaporation of this water would deposit on the surface whatever salts it held in solution. In the majority of cases even with a porous sandy subsoil it will be found that underdrainage will hasten the reclamation to such an extent that the income from the land in consequence of the rapid reclamation will pay for the cost of installing drainage. It is also to be noted that in a district with a high water table, if any large tracts of land are heavily flooded for long periods, the water table will be materially raised; so while it may be possible to reclaim a small tract without drainage it will be more difficult to reclaim large districts without providing some outlet for the excess of water used.

While the alkali question is at present of vast importance and demands serious consideration, indications point to its complete solution in the more important irrigated districts. In many of these districts extensive agricultural industries have been developed and good lands command high values. The time is soon coming when the farmer can not afford to allow alkali lands to lie waste and barren when the expenditure of comparatively small sums of money will make them productive. Intelligent land owners, as well as parties looking for profitable investment, will study the alkali question more carefully to determine just what methods will give them returns on apparently worthless lands with the least outlay of capital.

Constant search for more resistant crops will be made and the utilization of large areas of alkali land will be brought about in this way. Cultivation to mix the surface accumulations of alkali with the deep soil will also render some lands suitable for certain classes of crops. Surface flooding on carefully leveled fields will, in many instances, so reduce the alkali content in the upper layers of soil that some revenue may be derived from lands now abandoned as unproductive. The use of gypsum on lands containing black alkali will also increase the areas of reclaimed land and doubtless other methods of treatment will be found by those interested in returning once fertile lands to their former condition. These means are being successfully used to some extent in many districts at the present time and offer a strong incentive to other farmers by the same or other methods of treatment to attempt the reclamation of at least a portion of their alkali lands.

By their individual efforts, then, the farmers should strive to reduce the acreage of alkali on their farms until the time comes when the subject of regional drainage is provided for in each district. When that time comes the control of alkali will cease to be the vital problem that it is to-day.

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